San Jose State University
SJSU ScholarWorks

Master's Theses | Master's Theses and Graduate Research

1990

Design and construction of a laboratory-scale liquid-injection continuous-flow incinerator

Ilsok Kang
San Jose State University

Follow this and additional works at: https://scholarworks.sjsu.edu/etd_theses

Recommended Citation

Kang, Ilsok, "Design and construction of a laboratory-scale liquid-injection continuous-flow incinerator" (1990). *Master's Theses*. 57.
DOI: https://doi.org/10.31979/etd.jvmf-e3db
https://scholarworks.sjsu.edu/etd_theses/57

This Thesis is brought to you for free and open access by the Master's Theses and Graduate Research at SJSU ScholarWorks. It has been accepted for inclusion in Master's Theses by an authorized administrator of SJSU ScholarWorks. For more information, please contact scholarworks@sjsu.edu.

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

U·M·I

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

Order Number 1342719

Design and construction of a laboratory-scale liquid-injection continuous-flow incinerator

Kang, Ilsok, M.S.

San Jose State University, 1990

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

DESIGN AND CONSTRUCTION OF
A LABORATORY-SCALE LIQUID-INJECTION
CONTINUOUS-FLOW INCINERATOR

A Thesis

Presented to

The Faculty of The Department of Chemical Engineering

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

Ilsok Kang

December, 1990

APPROVED FOR THE DEPARTMENT OF CHEMICAL ENGINEERING

Dr. Sonia Kreidenweis, Professor

Dr. Michael Jennings, Professor

Dr. Robert Johnk, Professor

APPROVED FOR THE UNIVERSITY

M. Lou Lewandowski

ABSTRACT

DESIGN AND CONSTRUCTION OF
A LABORATORY-SCALE LIQUID-INJECTION
CONTINUOUS-FLOW INCINERATOR

by Ilsok Kang

The feasibility of developing a student laboratory for the thermal destruction of model hazardous wastes in a continuous-flow, liquid-injection incinerator was investigated.

The proposed system was found to be versatile in the type of feeds that can be used, and is simple to operate and maintain. A detailed design for the incinerator, including auxiliary support equipment, is presented, with specifications for all parts. All flow, pressure, and temperature measurement systems have been assembled. These are automated and have been interfaced to a laboratory computer that has been configured for experimental data acquisition. Since the unit is to function as a laboratory, special care has been taken in design of safety features. In particular, a flame safeguard system that complies with current fire safety standards has been designed, constructed and tested.

ACKNOLEDGEMENTS

It is a pleasure to acknowledge the assistance of many persons in this work, especially Dr. Sonia Kreidenweis who came up with the topic of this thesis and provided her continued guidance and instruction regarding this work.

In addition, I would like to express my profound gratitude to Dr. Michael Jennings for obtaining the necessary technical support for this venture, and to Dr. Robert Johnk and Dr. Sonia Kreidenweis for their assistance during revision of the manuscript.

Special thanks also go to Mr. Steve Londerville of COEN company for providing valuable information on a data acquisition system and flame safeguard, as well as for donation of the burner system, including the liquid atomizer, which was specially designed for our laboratory unit.

Finally, I would like to thank Dan Vroom for his help, and my family and wife for their patience and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

1.1 Background

Hazardous wastes, in the form of gases, liquids, solids or sludges, are produced continuously in industrialized societies. The challenge is to manage such wastes while minimizing air, water, and soil contamination. The traditional, untreated methods of disposing of hazardous wastes in landfills, lagoons, and injection wells require disposal sites and present potential contamination hazards, as well as high costs. These are being replaced by alternative disposal methods, such as physical/chemical/biological treatment [1] or thermal destruction (incineration). Advantages of incineration as a waste disposal method include reduced waste volume and possible energy recovery. In current incineration technologies, hazardous wastes are burned, with or without auxiliary fuels, at high temperatures, above 900 degrees celsius, in industrial furnaces, cement kilns, or boilers. Tests of properly-designed thermal destruction systems have proven their capability of achieving high overall degrees of destruction for a broad range of hazardous waste organics. It is believed that incineration will become one of the major treatment technologies for organic waste destruction, particularly as disposal sites become less available and as the numerous environmental catastrophes resulting from improper or inadequate disposal practices are discovered.

A number of incineration technologies have been developed for handling hazardous wastes. The well-established incinerator designs are:

- Rotary Kiln
- Fixed Hearth
- Liquid Injection
- Fluidized Bed
- Circulating Bed

Since many useful design guides and examinations of design principles have been published [2,3,4], a detailed discussion of the various technologies are beyond the scope of this paper. Here, we will focus on our choice for investigation, which is "liquid injection."

There are several reasons for the selection of liquid-injection incineration as our laboratory model. According to estimates by the Congressional Budget Office, about 20% of the total hazardous wastes generated each year contain organics and can be incinerated. Table 1 contains the estimates of total and incinerable wastes generated in 1983. About 43% of the total liquid waste is waste oils. Among 285 incinerators (1987 data) in the EPA hazardous waste data management system [5], the liquid-injection type of incinerator was most widely used in the U.S.A.. Other attractive features of the liquid-injection incinerator are its relative simplicity and its applicability to the study of fluid flow and atomization principles. Of the alternative reactor designs,rotary kilns are mostly widely used since they can handle a large variety of feedstocks, including drums, solids, and liquids. However, they are generally applicable to large-scale operations. Fluidized-bed incinerators are increasingly used in industry for handling inorganic residues, such as sodium sulfate and sodium chloride; however, gas residence times are short, and an after-burner is usually required in order to achieve the necessary burnout. The simplicity of the liquid-injection process makes it convenient to examine process variables. After consideration of these points, the liquid-injection system was chosen for use in our engineering laboratory.

Table 1. Quantities of Incinerable Wastes Generated in the U.S.A. 1983

Type of Waste	Quantity Generated (MMT)	Current Percentage Recycled/ Recovered	Quantity After Recyled/ Recovered (MMT)
Liquids:			
Waste oils	14.25	11	12.68
Halogenated solvents	3.48	70	1.04
Nonhalogenated solvents	12.13	70	3.64
Other organic liquids	3.44	2	3.37
Pesticides/berbicides	0.026	55	0.012
PCB	0.001	0	0.001
Total liquids	33.33	38	20.74
Sludge and Solids:			
Halogenated sludges	0.72	0	0.72
Nonhalogenated sludges	2.24	0	2.24
Dye and paint sludges	4.24	0	4.24
Oily sludges	3.73	5	3.54
Halogenated solids	9.78	0	9.78
Nonhalogenated solids	4.58	0	4.58
Resins, latex, monomer	4.02	65	1.41
Total sludges/solids	29.31	10	26.51
Total incinerable wastes	62.64	25	47.25
Total hazardous wastes	265.60	6	249.28

MMT = millions of metric tons

Source: E. Timothy Oppelt,"Incineration of Hazardous Waste A Critical Review," JAPCA 37:559(1987).

1.2 Combustion Fundamentals and Parameters [6]

Knowledge of air movement, fuel characteristics and heat and mass transfer rates is required for understanding the combustion process. To initiate and maintain combustion, three elements must be present. These are fuel, oxygen, and an ignition source; in waste incineration, the waste often serves as fuel if it has a high enough heating value. In this work, the terms "fuel" and "waste" are used interchangeably. The oxygen usually comes from ambient air, which contains about 21% oxygen and 79% nitrogen by volume. The fuel is composed mainly of carbon and hydrogen. Some fuels contain other components, such as oxygen, sulfur, chlorine, nitrogen, and inorganics. A simplified combustion reaction can be described as the rapid oxidation of fuel accompanied by the production of heat:

$$C \text{ (in the fuel/waste)} + O_2 \longrightarrow CO_2 + \text{Heat}$$

$$H_2 \text{ (in the fuel/waste)} + O_2 \longrightarrow H_2O + \text{Heat}$$

$$\text{Halide (in the fuel/waste)} \longrightarrow \text{Acid (if sufficient hydrogen present)}$$

More commonly, fuel and air enter the combustion zone and must mix before reaction is possible. In complete combustion, the conversion of all carbon in the fuel into carbon dioxide (with a trace amount of carbon monoxide), that of all hydrogen into water or some inorganic acids, and that of all chlorine into hydrogen chloride with some chlorine gas (Cl_2), can be described by no reaction above for chlorine. Assuming complete combustion, the majority of sulfur will be converted to sulfur dioxide (SO_2), and nitrogen will be converted into different forms of oxides of nitrogen (NO_x) depending on combustion conditions. Equilibrium can be approached in the high temperature oxidation of organics, for which the reaction rate is very fast. However, true equilibrium is seldom reached, due to mixing and kinetic limitations which slow the overall reaction rate. At the slower rate, the fuel/air mixture does not have sufficient residence time at high temperature for complete conversion. In incomplete combustion, organics are decomposed into smaller species. Products of incomplete combustion (PICs: aldehydes, ketones, alcohols, and acids) are formed as these fragments combine with oxygen or hydroxide radicals.

For a process to approach complete combustion, fuel molecules and intermediate decomposition products must be mixed with oxygen in the proper proportions and ignited. Good mixing is also required and the mixture must be held at a high enough temperature, as well as for a long enough residence time, to achieve high combustion efficiency and correspondingly low emissions of partially oxidized products. Consequently, thermal decomposition technologies focus on three parameters: residence time, temperature, and turbulence (mixing). Here, we focus on how these variables are designed for liquid-injection systems.

1.3 Combustion of Liquid Fuels or Liquid Wastes in A Liquid-Injection Incinerator [7,8,9]

In conventional liquid-injection incinerators, liquid fuels are introduced through the burner assembly, sprayed into the combustion chamber as relatively fine droplets, and burned in suspension. Three basic processes are involved in the combustion of liquid wastes. These are: formation of droplets, heating and vaporization of droplets, and kinetically-dependent ignition and combustion of vapor. The combustion process is complicated by heat and mass transfer between the droplets and the surrounding gas phase.

The most important portion of the liquid-injection incinerator is the burner through which wastes and air are delivered. Once sprayed or atomized, the waste must be thoroughly mixed with sufficient air (primary air or combustion air) to provide oxygen for combustion. The primary air is introduced through baffles in a wind-box designed to impart swirl to the air and increase turbulence (and hence mixing). Minimum primary air pressure required for safe burner operation must be established prior to attempting ignition. Ignition of the combustible mixture of atomized waste and air is accomplished by its exposure to gases which are already circulating within the burner zone and are above the ignition temperature. Thus, the combustion chamber must be brought to a prescribed temperature using conventional fuels before the waste is introduced. If the waste has a high enough heating values, combustion may be sustained using waste alone, once a steady state is achieved.

CHAPTER 2. OBJECTIVES

The ultimate objective of the project described is to design and build a laboratory-scale, liquid-injection, continuous-flow incineration system.

There are three projected uses for this unit: educational, experimental, and research. The primary function of the incinerator is as a laboratory, to demonstrate concepts for undergraduate courses in chemical engineering. These concepts include flow in tubular pipes, overall gas-phase reaction kinetics, adiabatic flame temperature, heat recovery, fuel heating values, and emission concentrations. For this function, the incinerator will be used to combust a well-known liquid fuel, kerosene. A second function of this unit is to add a laboratory component to ChE 177, Combustion and Air Pollution Sources. Experiments will be designed to demonstrate the dependence of pollutant formation on fuel composition and combustion temperature, and the dynamic response of the combustion flue gas composition to changes in operating parameters, for example, the ratio of "wastes" to combustion air. For this function, model "hazardous wastes" can be selected; for example, a polymer blend with low heating values. A third function of the laboratory is to generate student projects in combustion research and in related areas, such as stack gas treatment and automated process control. The unit is to be supplemented by a computerized data acquisition system that will record the flow rate measurements for air, natural gas, and waste oil, temperature measurements, and emissions concentrations measurements. It is the specific goal of this work to design, construct, and test the data acquisition system and the control and safety features of the incinerator.

CHAPTER 3. DESIGN APPROACH

3.1 Design Criteria

In addition to the design considerations discussed in the introduction, regarding efficiency of combustion of the wastes, an operating hazardous waste incineration system must meet guidelines established by the Environmental Protection Agency (EPA). This section gives an overview of performance criteria required for compliance.

There are several national performance standards that must met (see Appendix F for a detailed discussion). The first of these requires 99.99% destruction and removal efficiency (DRE) for each principal organic hazardous constituents (POHC) [10] in the waste feed.

$$DRE = \frac{Win - Wout}{Win} \times 100$$

where Win = Mass feed rate of POHC in waste stream fed to the incinerator

Wout = Mass emission rate of the POHC in the stack prior to release to the atmosphere

Second, at least 99% of hydrogen chloride in the exhaust gas should be removed if hydrogen chloride stack emissions are greater than 1.8 Kg/Hr. Last, particulate matter emissions must be no greater than 180 mg/m3, corrected to 7% oxygen in the stack gas.

Another set of design criteria are the operational standards [11] that require a device to automatically shut off the waste feed to the incinerator when significant changes occur in flame temperature or excess air. For incineration of hazardous waste, the operating temperature, gas residence time, and excess air should be greater than 1000 deg C, 2 seconds, and 2 percent respectively. In case of waste which contains halogenated aromatic hydrocarbons, the incinerator should be operated at greater than 1200 deg C operating temperature, 2 seconds residence time, and 3 percent excess air. Combustion efficiency should be equal to or greater than 99.9 percent, where

$$CE = \frac{Cco2}{Cco2 + Cco} \times 100$$

CE = Combustion efficiency

Cco2 = Concentration of CO2

Cco = Concentration of CO

Also, process variables should be monitored and recorded in each operational burn: combustion temperature, CO and CO2 concentrations in the exhaust gas on a continuous basis, and feed rate of waste, fuel, and excess air to the incineration system at regular intervals of no longer than 15 minutes.

3.2 Design Basis

Before the process design can be properly embarked on, a certain body of information should be agreed upon by all concerned persons. This is called the design basis and is here broken into seven parts.

3.2.1 Location of Incineration System

The system is to be located in the courtyard of the Engineering Building. An outdoor location was chosen to minimize potentially hazardous conditions, by providing ventilation in case hazards occur (such as leakage of small amounts of fuel oils having high volumetric heats of combustion, or leaks in gas piping routed through confined areas). In addition, the cost of fire control systems for an internal location would be prohibitive. Analytical equipment, including the emissions analyzer and personal computer, will be portable, and can be moved from storage inside the laboratory to the courtyard for experimentation.

3.2.2 Physical Properties of Liquid Fuels To Be Tested [12,13]

At this design level, a maximum range of properties is specified, since actual fuel/wastes are unknown. Kerosene and Bunker C oil represent the typical range of properties expected.

	KEROSENE (LIGHT OIL)	BUNKER C (HEAVY OIL)
VISCOSITY	2 CP at 68°F	60 CP at 210°F
GRAVITY (API)	44 - 49	15
SPECIFIC GRAVITY	0.81 - 0.78	0.97
DENSITY (LB/GAL)	6.75 - 6.5	8.1
FLASH POINT (F)	110 - 130	
AUTOIGNITION TEMP (F)	490	765
FIRING TEMP (F)	68	210
HEATING VALUE (BTU/LB)	20000 - 210000	18000

3.2.3 Combustion Chamber Unit

The combustion chamber dimensions were chosen to provide flexibility in reaction time, minimum size, and based on scales of analytical and control equipment. The combustion chamber will have a 2.875-inch inside diameter (2.5-inch, Sch 40 Pipe) and be 6-feet long. Horizontally-aligned chambers are used for low ash wastes, while vertical units are preferred when wastes are high in inorganic salts and fusible ash content. Since the liquid wastes to be incinerated will not contain high ash, and a horizontal combustor is easier to inspect and service, the combustion chamber will be mounted horizontally.

3.2.4 Burner Unit

An air-atomizing oil burner, of capacity 20,000 BTU/HR, will be specially designed for the laboratory model by COEN company. The burner will receive combustion and atomization air and/or steam and liquid at the firing temperature.

3.2.5 Fuel Oil Storage Tank

A 17-inch inside diameter and 33.5-inch height storage tank, including agitator and heater, was adapted for use in this project. The tank hold enough material for six hours of operation and has double-wall design to contain leaks.

3.2.6 Residence Time

Based on published guidelines, it was decided that the amount of time that the liquid waste must spend in the incinerator, at a given temperature, will be at least one second.

3.2.7 Available Utilities

150 lb/hr at 100 psi of compressed air and 12 inches water column of natural gas are available from a nearby engineering laboratory. Water and electric power are available in the courtyard.

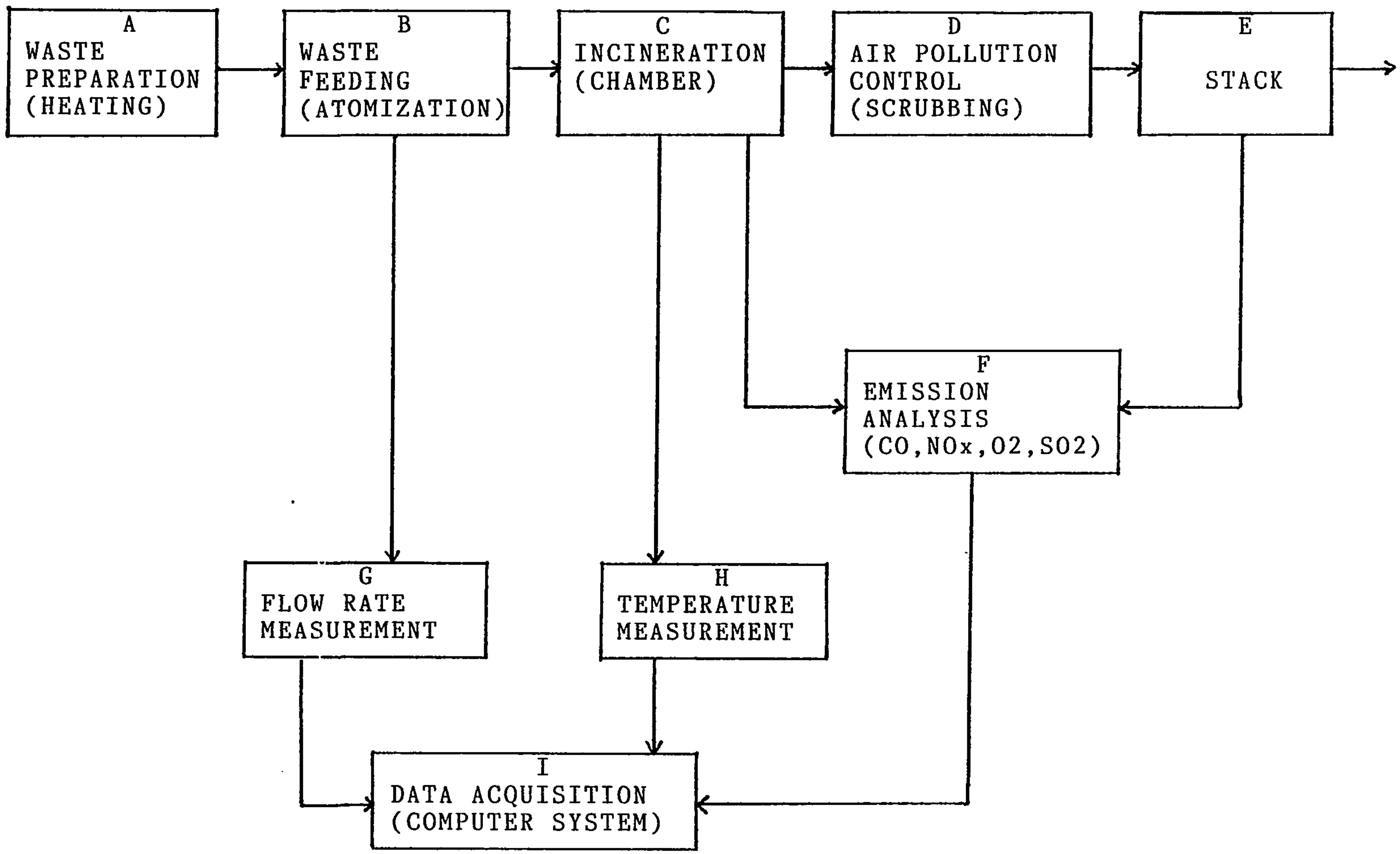
CHAPTER 4. DESCRIPTION OF INCINERATION SYSTEM

4.1 Overview of The System

A block diagram showing individual processes (Figure 1) or group of operations, provides an overview of the incineration process. Please refer to notation on that figure in the following description of the process.

Liquid wastes must be pumpable and atomizable. Wastes are to be blended, or heated for heavy-viscosity liquid waste, then pumped from waste preparation (A) into the combustion chamber (C) through a specially-designed atomizing burner (B). Atomized liquid, in the form of fine droplets, is mixed in the burner with excess primary air to promote complete combustion. The ignitable mixture of atomized liquid (fuel and/or waste) and air burns in the combustion chamber. Following incineration, flue gases may need to be further treated in an air pollution control device (D), such as a packed tower absorber (acid gas removal), quench (gas cooling and conditioning), venturi scrubber (particulate removal), or dry scrubber for gaseous pollutant control. Combustion gases (flue gases) are sampled at several places through the combustion chamber and stack (E) and sent to the emissions analysis system (F) to determine concentration of

FIGURE 1. BLOCK FLOW DIAGRAM



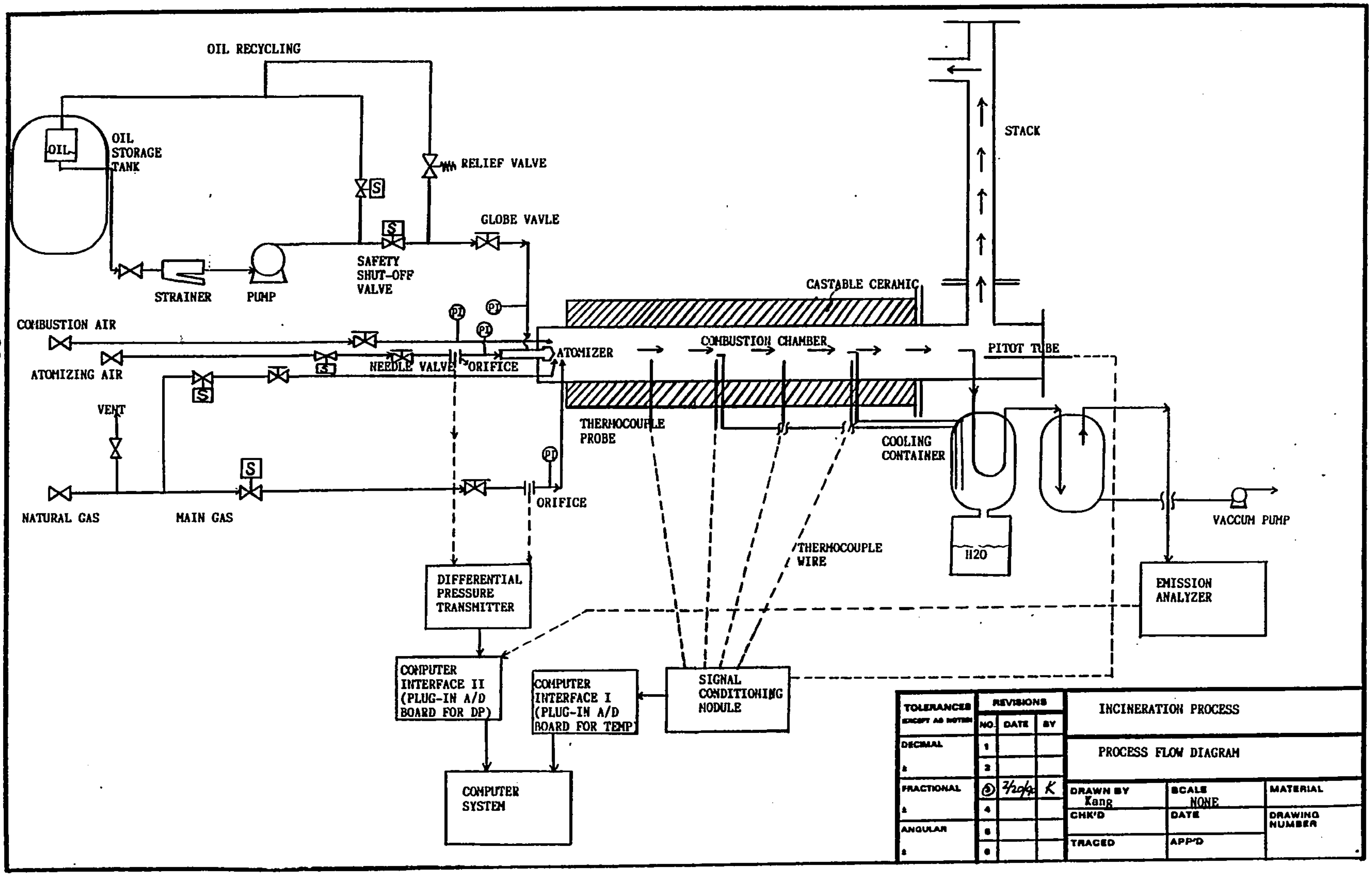
CO_2, CO, NO, O_2, SO_2. These are monitored with respect to changing process parameters, such as the ratio of liquid and air flow rates. The flow rates of liquid wastes, air, and natural gas are calculated by the computer from the differential pressure measurement (G) across orifice taps. Temperature profiles through the combustion chamber and the temperature of the liquid waste in the tank will be recorded (H) by the data acquisition system (I).

4.2 Process Description

Figure 2 shows the process flow diagram for the incinerator. The incineration system is divided into six subsystems: burner and flame safeguard control, combustion chamber and stack, flow rate and temperature measurement with data acquisition, piping and instrumentation, and sampling and emission analysis.

Liquid wastes or fuels in the storage tank must be prepared to ensure good atomization, which is required to achieve high destruction efficiency in the chamber. In order for a high viscosity liquid waste to be blended and delivered easily to the atomizing burner, a section heater (to lower oil viscosity) is installed in the storage tank.

FIGURE 2. PROCESS FLOW DIAGRAM



Wastes containing suspended particles may need to be screened to avoid clogging of small nozzle or atomizer openings. A strainer with particle retention size of 250 mesh is installed before the pump to remove such particles.

In our laboratory-scale system, a combination burner that is capable of burning gas or oil, or both, is installed at the front of the combustion chamber. In the atomizing burner, the prepared liquid wastes are atomized by compressed air at 30-40 psi into small droplets. These fine droplets must be vaporized before combustion can occur. This is usually accomplished by the initial heating from the flame. Vaporized fuel or waste is mixed with atmospheric air, which is pulled by a duct air fan beyond the burner nozzle. The mixture of vaporized waste and air will be ignited by its exposure to gases which are already circulating within the burner zone and are above the ignition temperature.

At startup, ignition is accomplished by a direct spark ignition unit, including spark igniter and flame sensor. The spark ignites the pilot gas directly, and then the pilot flame ignites the main burner. The burner system will be automatically controlled by a flame safeguard control unit in order to start, stop, or shut down safely. The control unit translates inputs from the flame detector (flame rod), which senses the presence or absence of a flame, so that burner operation may be continued if conditions are safe, and interrupted if they are not. The inputs are used for sequenced control of the burner motor, ignition, and main liquid waste valve.

The ignited mixture is combusted in the chamber, and released to the atmosphere through the stack. The combustion chamber is a cylindrical, steel shell (6-inch inside diameter and 6-foot long) lined with a refractory material (castable ceramic). This is a non-metallic substance which can resist abrasion and endure high temperature (up to 3000° C), and is required since the interior of the incinerator can reach temperatures above 2000°C. The chamber is mounted in a horizontal position and the stack is vertically flanged at the end of the chamber.

Flow rates of liquid waste, air, and natural gas, temperature profiles through the combustion chamber, and emissions concentrations will be collected and simultaneously displayed on a computer screen. The data acquisition (computer interface system) converts the signals produced by the pressure transmitters and temperature sensors into a form that the computer can understand. Produced signals (currents or voltages) can be converted into the actual data by calibrated correlations between signals and actual data. A detailed description of the data acquisition system is in Chapter 6.

For safety of personnel and protection of property, careful consideration is given to the supervision and monitoring of conditions which may present a hazard. In this system, solenoid valves are used as safety shutoff valves for the liquid waste, atomizing air and natural gas lines. These are installed and integrated with the flame safeguard control unit. A detailed description of piping and instrumentation, including the interlocks and set point limits, is found in the following section.

Accurate and proper measurement of the emission from the incineration system is a critical measure of process performance. The EPA has provided guidance on the types and methods of sampling and analysis to be used in trial burns designed to measure facility compliance with the Resource Conservation and Recovery Act (RCRA) incinerator standards. A complete sampling system [14] operating continuously and unattended, is comprised of three major subunits: a pitot tube probe for temperature and velocity measurements and for gas sampling; a water trap unit with filter to trap particles of soot and fly ash and to remove excess moisture; and sensors to analyze oxygen, carbon monoxide, NOx, sulfur dioxide, and combustibles. A detailed description of the emission analyzer used in this work appears in the following chapter.

4.3 Piping and Instrumentation

The piping and instrumentation flowsheet (Figure 3) displays sizes of and specifications for all tubings and pipes, temperature and pressure switches, gages, and all valves, including safety valves. The proposed liquid fuel or waste flow rate, using the design basis in section 3.2 and the relation between pipe size, volumetric flow rate, and velocity, is given by

$$V = \frac{Q}{d \times NHV}$$

where, V : Maximum Volumetric Flow Rate of Kerosene

Q : Maximum Heat Release (20,000 Btu/Hr)

d : Density of Kerosene (7 Lb/Gal)

NHV : Net Heating Value of Kerosene (20,000 Btu/Lb)

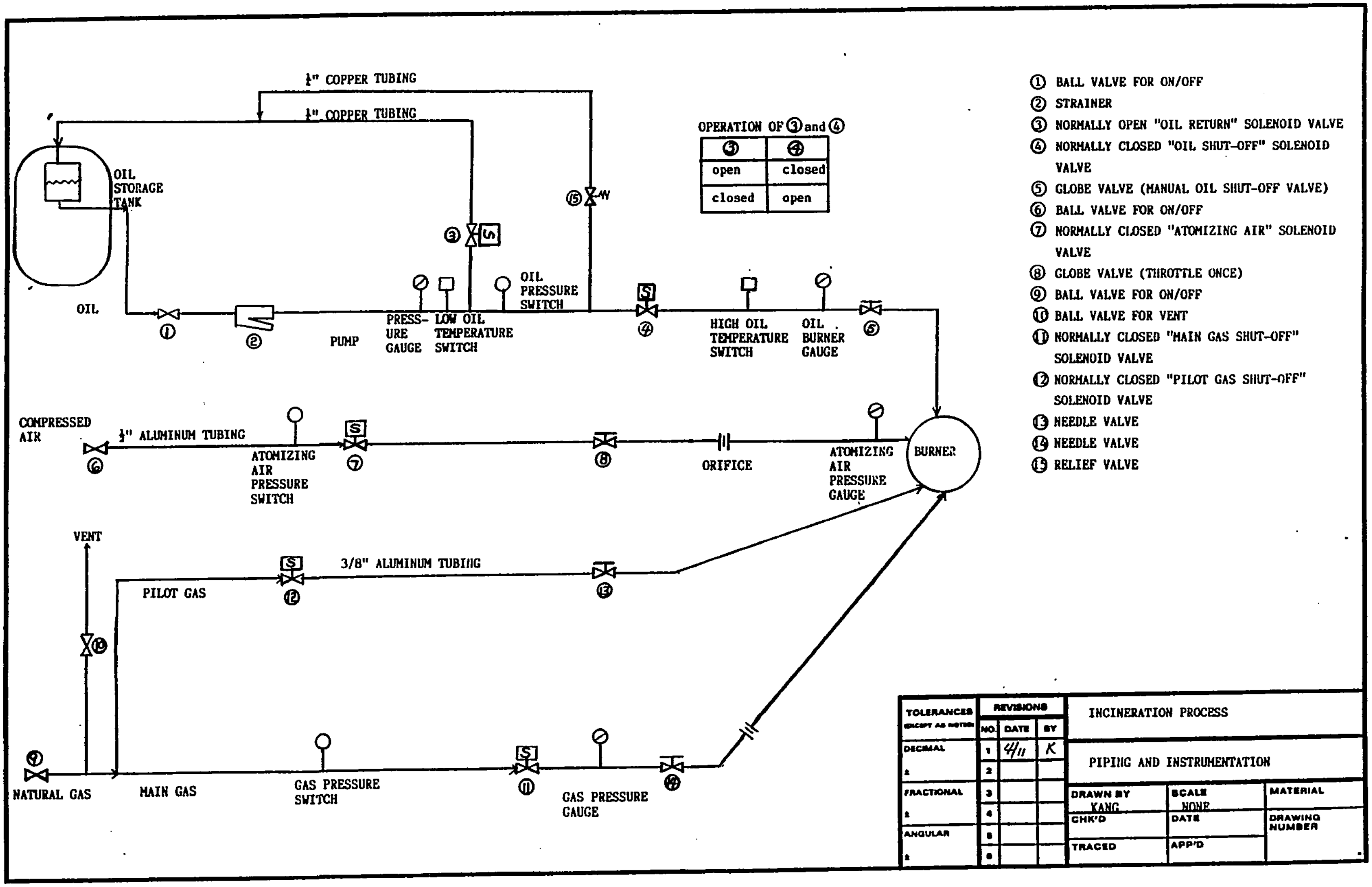
$$V = \frac{(20{,}000 \text{ Btu/Hr})}{(7 \text{ Lb/Gal}) \text{ X } (20{,}000 \text{ Btu/Lb})}$$

$$= 0.14285 \text{ Gal/Hr}$$

$$= 0.002381 \text{ Gal/Min}$$

$$= 9.012 \text{ Cm3/Min}$$

FIGURE 3. PIPING AND INSTRUMENTATION



The calculation shown is for kerosene. To convert to other fuels, the maximum heat release Q must be kept constant and V is calculated for the fuel's NHV.

The required tubing size for the liquid waste will be 1/8 inch nominal diameter. A detailed calculation will be shown in the pump part of the next chapter. Tubing sizes required for the atomizing air and natural gas lines will be 1/2 inch nominal diameter. Calculation of the pressure drop across the orifice union will be shown in the next chapter. The selection of the tubing material depends on the corrosive nature of the fluid and on the flow pressure. Copper tubing for the liquid waste, annealed aluminum tubing for air, and stainless steel tubing for the natural gas line will be used.

To control the amount of flow, or to stop the flow completely, several different types of valves have been selected. Ball valves will be used for on-off control of all lines. The liquid waste and compressed air flows will be adjusted by globe valves, while the smaller natural gas flow will be adjusted by a needle valve for greater accuracy. Pressure gages for all lines and a temperature gage for the liquid waste are installed upstream of the burner unit.

Safety shutoff valves for the liquid waste and natural gas lines are the most important components of the safety shutdown system. Oil safety shutoff valves will automatically shut off liquid waste to the burner unit within 5 seconds after interruption of the holding medium by any one of the interlocking safety devices. As an interlocking safety device, at least one low pressure switch will be provided for each safety shutoff valve. Whenever the normal pressure in each line exceeds the design limits (either the low limit or the high limit), one of the pressure switches will activate the burner unit's safety shutoff valve. Low and high temperature switches are installed to protect against exceeding a safe limit for the liquid waste temperature. All instruments are installed in a metal cabinet, 48"Lx36"Wx16"D, for protection from the environment. Figures 4 and 5 show the arrangement of the instruments in the cabinet and the location of the system.

FIGURE 4. ARRANGEMENT OF INSTRUMENTS IN THE CABINET

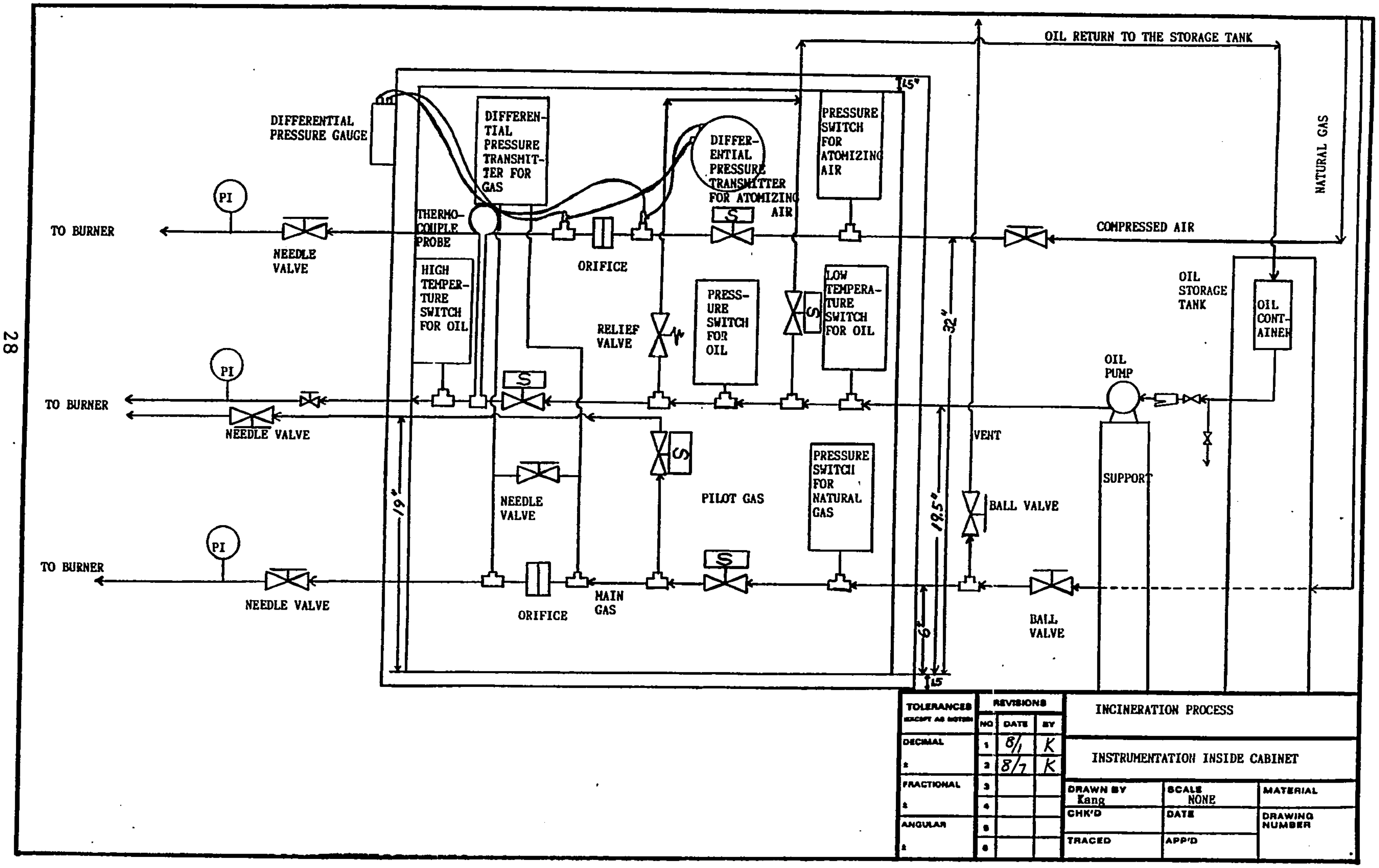
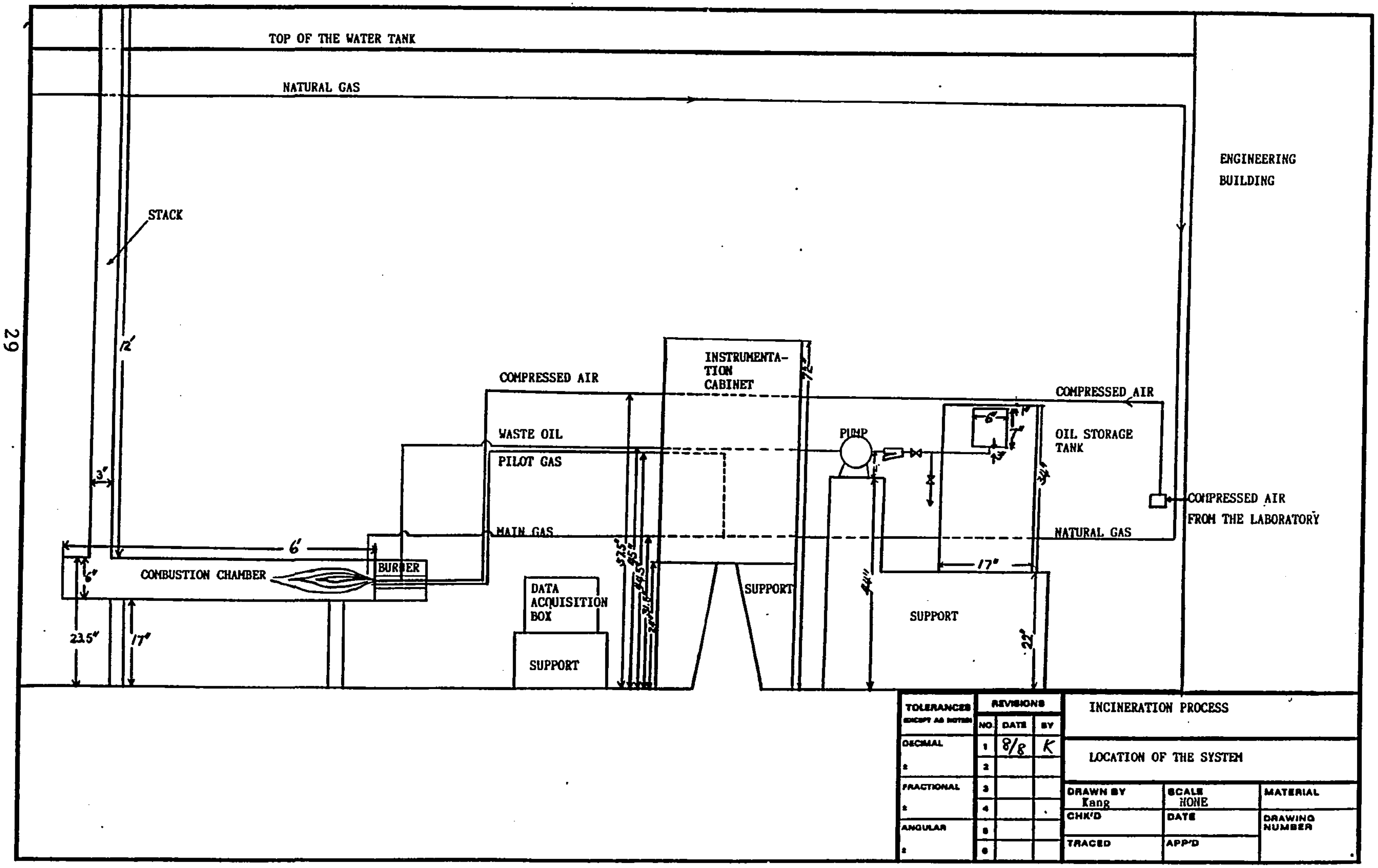


FIGURE 5. LOCATION OF THE SYSTEM

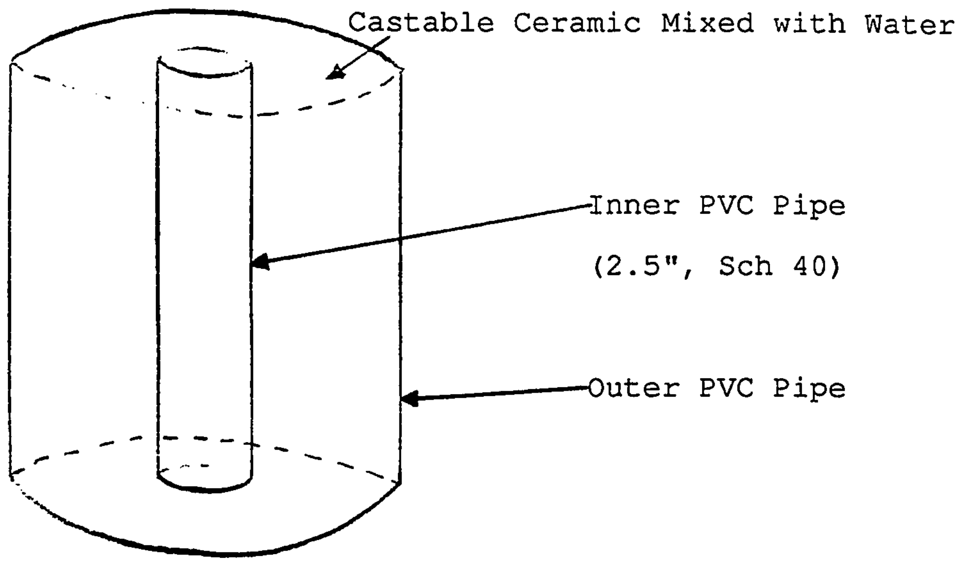


CHAPTER 5. DESCRIPTION OF EQUIPMENT

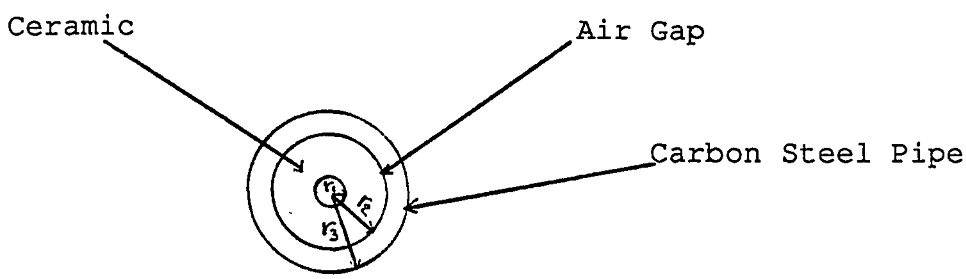
5.1 Combustion Chamber and Stack

A 6-foot long and 2.875-inch inside-diameter refractory pipe was molded from castable ceramic. Powdered castable ceramic, PLICAST KL MIX (Al_2O_3:53.3%, SiO_2:39.2%), mixed with an appropriate amount of water was poured into a mold made from two PVC pipes (Figure 6). After curing of the ceramic, the outer PVC pipe was taken off, and the inner pipe will be removed by burning. This ceramic liner will be inserted into a 6-foot long carbon steel pipe and flanged to the stack. This procedure allows for easy replacement of the liner if it becomes cracked or eroded, without necessitating replacement of the outer steel pipe.

Figure 6. Castable Ceramic Molding



The required thickness of castable ceramic is estimated to maintain a low temperature on the outer surface of incinerator for safety reasons. The thickness of castable ceramic is estimated as follows [15]:



Ti T1 T2 T2h T3 T4 To

————WW————WW————WW————WW————WW————WW————

R1 R2 R2h R3h R3 R4

Ti: Average temperature inside the chamber (assumed, 2200°F)

To: Ambient temperature outside the chamber (assumed, 80°F)

T1: Inner surface temperature of the ceramic liner

T2: Outer surface temperature of the ceramic liner

T2h: Average temperature of the air in the gap

T3: Inner surface temperature of the carbon steel pipe

T4: Outer surface temperature of the carbon steel pipe

r1: Radius of the inside ceramic liner (1.4375")

r2: Radius of the outside ceramic liner

r3: Radius of the inside carbon steel pipe (r2 = r3)

r4: Radius of the outside carbon steel pipe

R1 - R4: Thermal resistance for conduction and convection

R1 = 1 / 2xpixr1xLxhi — hi: Heat transfer coefficient inside the chamber

R2 = ln(r2/r1) / 2xpixkcxL — kc: Thermal conductivity of castable ceramic (0.6667Btu/hr ft F at 2000°F)

R2h = 1 / 2xpixr2xLxhc — hc: Heat transfer coefficient between the outer surface of the ceramic liner and air gap (assumed, 1.0)

R3h = 1 / 2xpixr3xLxhp   hp: Heat transfer coefficient between air gap and the inner surface of the steel pipe (assumed, 1.0)

R3 = ln(r4/r3) / 2xpixkpxL   kp: Thermal conductivity of the steel pipe (27 Btu/hr ft F)

R4 = 1 / 2xpixr4xLxho   ho: Heat transfer coefficient between the outer surface of the steel pipe and ambient air (assumed, 1.5)

$$Q = \frac{Ti-To}{SUM\_R} = \frac{Ti-T1}{R1} = \frac{T1-T2}{R2} = \frac{T2-T2h}{R2h} = \frac{T2h-T3}{R3h}$$

$$= \frac{T3-T4}{R3} = \frac{T4-To}{R4}$$

The outer surface temperature of the carbon steel pipe can be estimated by the heat transfer rate equation [15]. The internal heat transfer coefficient, hi, is estimated as follows:

Combustion Chamber

$\longrightarrow$ Flue Gas (Average Temp: 2200 F) $\longrightarrow$

* Maximum volumetric flow rate of flue gas (V)

$$V = \frac{\text{Volume of the combustion chamber}}{\text{Residence time}}$$

$$= \frac{(pi/4)x(2.875/12)\text{^}2x6 \text{ ft3}}{1 \text{ sec}}$$

= 0.2705 ft3/sec

* Average density of flue gas at the average temperature (d)

d = Density of air at 2200 F

= 0.015 lb/ft3

* Average viscosity of flue gas at average temperature (u)

u = Viscosity of air at 2200 F

= 0.121 lb/ft hr

* Maximum mass flow rate of flue gas (m)

m = dxV

= (0.2705 ft3/sec)x(0.015 lb/ft3)x(3600 sec/hr)

= 14.607 lb/hr

* Reynolds number (Nre)

Nre = (4xm) / (pixDxu)

= (4)x(14.607 lb/hr)/(pi)x(2.875/12)x(0.121 lb/ft hr)

= 642 : Laminar flow

* Nusselt number (Nnu)

Nnu = hixD / k = 4.36 for Laminar flow

hi = 4.36xk / D

= (4.36)x(0.10 Btu/hr ft F) / (2.875 ft/12)

= 1.8 Btu/hr ft2 F

The above numerical values are substituted in the heat transfer equation. The results are in Table 2.

Table 2. Surface Temperature (T4) of the Incinerator as a Function of Thickness of Castable Ceramic

	Pipe Size (Sch 40) 5.000"	6.000"	8.000"
Ti (F)	2200.0000	2200.0000	2200.0000
To (F)	80.0000	80.0000	80.0000
hi (Btu/hr*ft2*F)	1.8000	1.8000	1.8000
kc (Btu/hr*ft*F)	0.6667	0.6667	0.6667
hc (Btu/hr*ft2*F)	1.0000	1.0000	1.0000
hp (Btu/hr*ft2*F)	1.0000	1.0000	1.0000
kp (Btu/hr*ft*F)	27.0000	27.0000	27.0000
ho (Btu/hr*ft2*F)	1.5000	1.5000	1.5000
r1 (ft)	0.1198	0.1198	0.1198
r2 (ft)	0.2090	0.2527	0.3308
r3 (ft)	0.2090	0.2527	0.3308
r4 (ft)	0.2318	0.2644	0.3594
R1(1/2*pi*r1*L*hi)	0.1230	0.1230	0.1230
R2(ln(r2/r1)/2*pi*k	0.0221	0.0297	0.0404
R2h(1/2*pi*r2*L*hc)	0.1269	0.1050	0.0802
R3h(1/2*pi*r3*L*hp)	0.1269	0.1050	0.0802
R3(ln(r4/r3)/2*pi*k	0.0001	0.0000	0.0001
R4(1/2*pi*r4*L*ho)	0.0763	0.0669	0.0492
sR (Sum of R)	0.4754	0.4296	0.3731
Q ((Ti - To)/sR)	4459.5972	4935.1386	5682.4286
T1 (Ti - Q*R1)	1651.4260	1592.9298	1501.0058
T2 (T1 - Q*R2)	1552.6783	1446.3759	1271.3732
T2h (T2 - Q*R2h)	986.6760	928.3363	815.7169
T3 (T2h - Q*R3h)	420.6736	410.2966	360.0606
T4 (T3 - Q*R3)	420.2200	410.0772	359.5977

The surface temperature of the combustion chamber decreases as the diameter of the outer pipe increases. Six-inch Sch 40 PVC pipe is chosen as a reasonable size of the outer pipe for molding castable ceramic, although the surface temperature of the incinerator will be 410 F. This high temperature on the surface of the incinerator could pose a safety hazard and also contributes to heat loss. Adding a lay of external insulation eliminates these problems. The necessary thickness of the insulation is calculated by adding one more term to the previous calculation of the surface temperature of the incinerator.

Ti T1 T2 T2h T3 T4 T5 To

——ww——ww——ww——ww——ww——ww——ww——

R1 R2 R2h R3h R3 R4 R5

The temperature on the surface of kaowool should be less than 130 F.

$$Q = \frac{Ti - To}{R1+R2+R2h+R3h+R3+R4+R5} = \frac{T5-To}{R5}$$

R1, R2, R2h, R3h, and R3 are the same as for 6" pipe size.

R4 = ln(r5/r4) / 2xpixkkaoxL

R5 = 1 / 2xpixr5xLxho

$$Q = \frac{2200 - 80}{0.1230+0.0297+0.1050+0.1050+4e-5+R4+R5} = \frac{130 - 80}{R5}$$

$$\frac{2120}{0.36274+R4+R5} = \frac{50}{R5}$$

$$R5 = 0.00856 + 0.02358x(R4+R5)$$

$$R5 - 0.02415xR4 = 0.00877$$

$$\frac{1}{2xpixr5xLxho} - \frac{(0.02415) \times \ln(r5/r4)}{2xpixkkaoxL} = 0.00877$$

$$(1 / r5) - 1.2078 \times \ln(r5/0.2644) = 0.4960$$

By trial and error, r5 = 0.64 ft. Thus, the thickness of kaowool is 0.3756 ft (4.5 inch). Table 3 shows the surface temperature of kaowool as a function of the thickness of kaowool insulation layer. The final design for the combustion chamber is shown in Figure 7, 8, and 9.

TABLE 3. SURFACE TEMPERATURE OF KAOWOOL AS A FUNCTION OF THE THICKNESS OF KAOWOOL INSULATION LAYER

THICKNESS OF OF KAOWOOOL(ft)	0.1	0.2	0.3	0.3756	0.4
r5 (ft)	0.3644	0.4644	0.5644	0.64	0.6644
T5 (F)	228.05	169.81	142.40	129.98	126.86

FIGURE 7. COMBUSTION CHAMBER

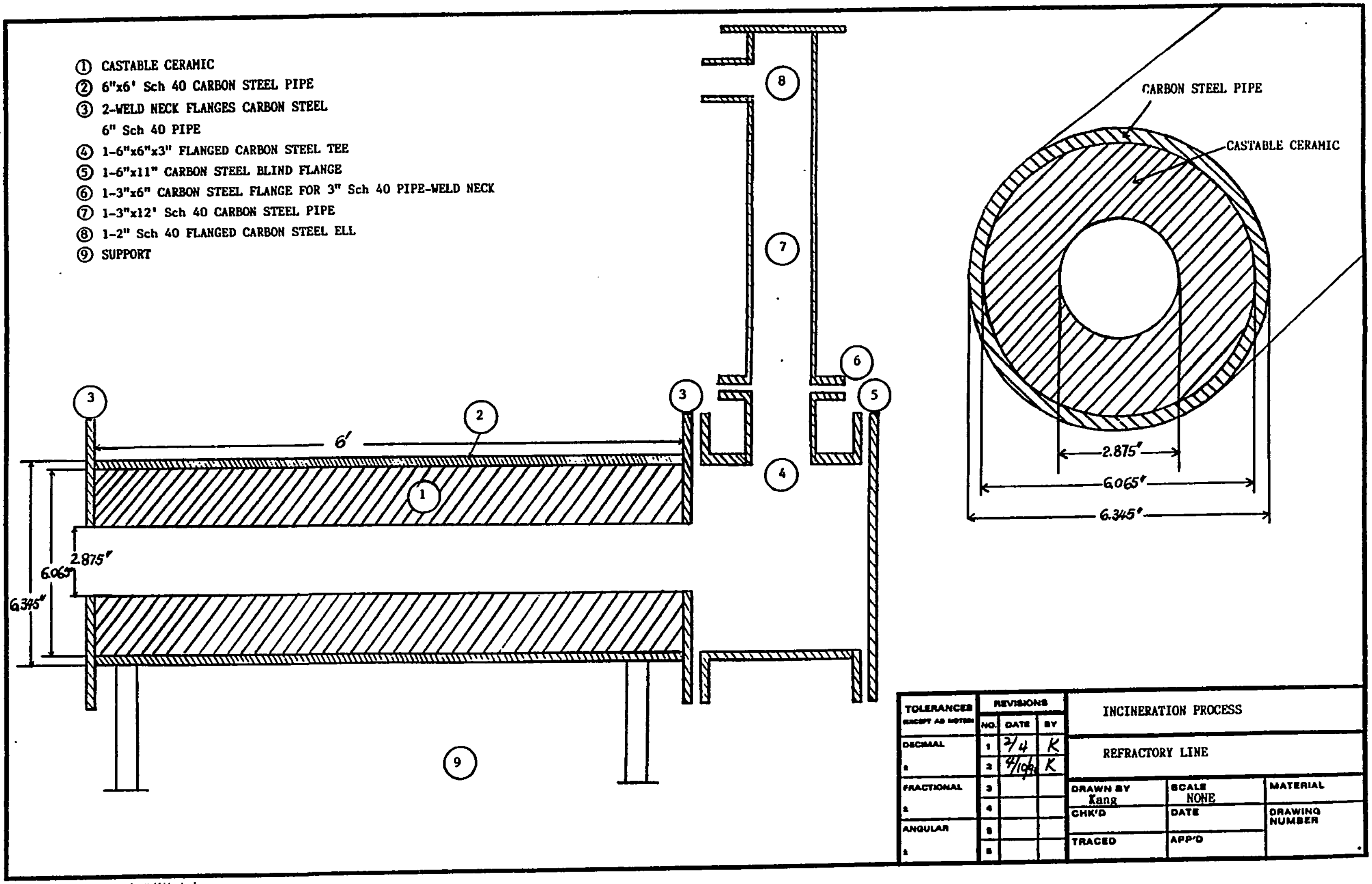


FIGURE 8. STACK

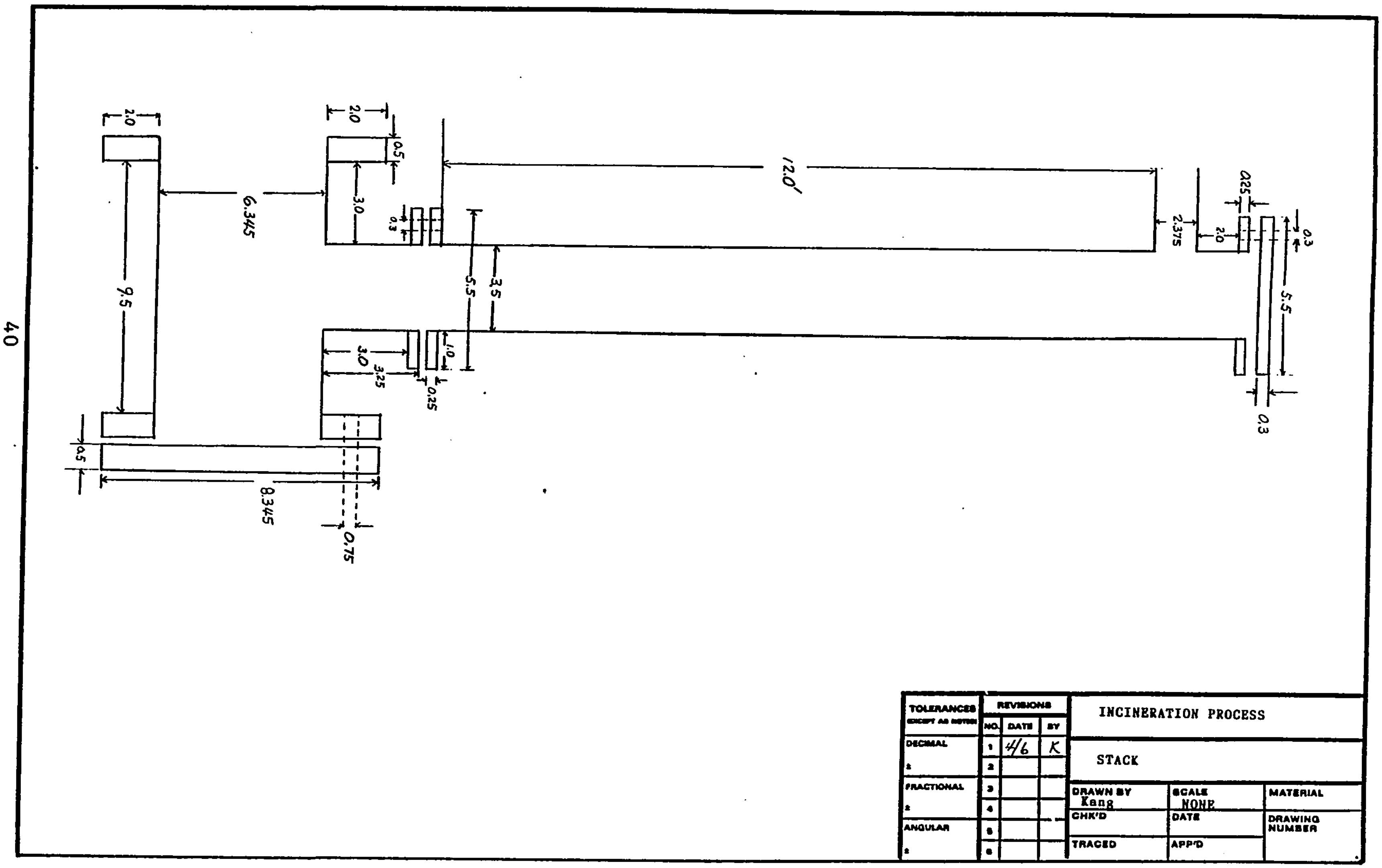
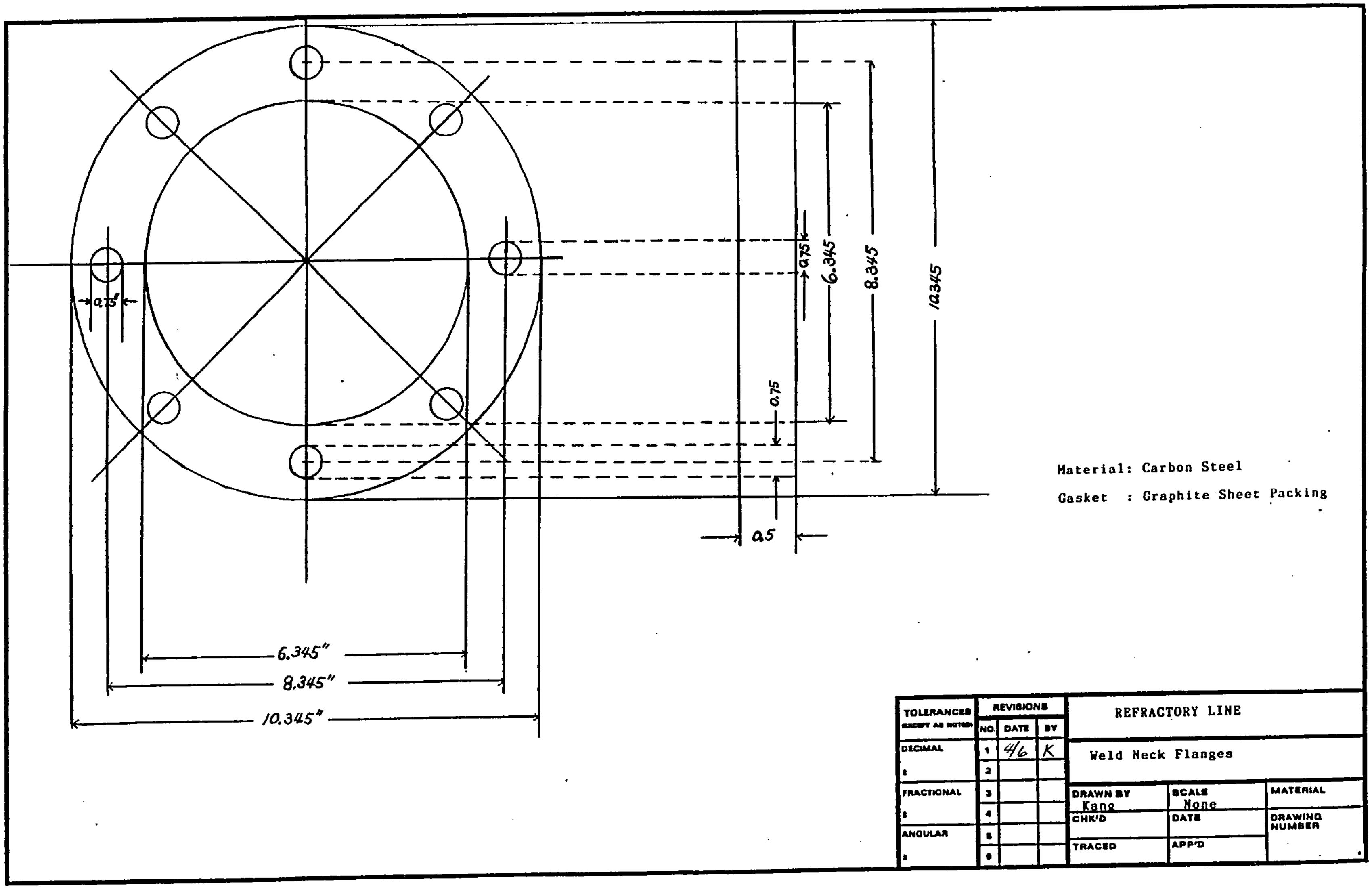


FIGURE 9. WELD NECK FLANGES



5.2 Waste Oil Pump

In order to select the pump system, the flow rate of waste oil is estimated by mass balance. The equation used to calculate the feed rate of waste oil, based on a 1 second residence time, is

$$\text{Feed rate(gal oil/sec)} = \frac{\text{Flue gas rate (ft3/sec)}}{\text{Volume of flue gas(ft3 gas/lb oil)} \times \text{Density of oil(lb oil/gal oil)}}$$

The maximum volumetric flue gas rate will be equal to the volume of the combustion chamber per second:
pixr^2xL = pix(0.1198)^2x6 = 0.2705 ft3, or 0.2705 ft3/sec
Again, calculations are performed for kerosene, since this fuel will be used for testing the incinerator. The density of kerosene is 7 lb/gal at 60 degrees F. The volume of flue gas per pound of kerosene fed into the incinerator is calculated using a simple mass balance based on stoichiometric air supply (combustion with no excess air).

* Gravimetric weight percentage of kerosene

C : 86.5	O : 0.1
H : 13.2	S : 0.1
N : 0.1	Ash : Neglect

* Convert wt% of each component to lbmol selecting 100 lb of kerosene as a basis

  C : 86.5/12 = 7.208 lbmol

  H_2 : 13.2/2 = 6.6 "

  N_2 : 0.1/28 = 0.00357 "

  O_2 : 0.1/32 = 0.003125 "

  S : 0.1/32 = 0.003125 "

* Primary combustion reaction for each component in fuel oil

  $C + O_2 \Longrightarrow CO_2$

  $H_2 + 1/2\ O_2 \Longrightarrow H_2O$

  $S + O_2 \Longrightarrow SO_2$

* Amount of oxygen required for each component

Component	lbmol in kerosene	lbmol of oxygen
C	7.208	7.208
H_2	6.6	3.3
S	0.003125	0.003125
O_2	0.003125	-0.003125
	Total :	10.508

Oxygen present in kerosene reduces the air requirement. Thus, the amount of oxygen in kerosene has been subtracted from the amount of oxygen required. Total required oxygen, based on no excess oxygen, will be 10.508 lbmol O_2/100 lb kerosene.

* Amount of nitrogen required for each component

$$\text{Amount of N}_2 = \text{Amount of O}_2 \times \frac{0.79 \text{ lbmol N}_2}{0.21 \text{ lbmol O}_2}$$

$$= 39.53 \text{ lbmol}$$

N_2 in kerosene = 0.00357

Total required N_2 = 39.53 - 0.00357

= 39.526 lbmol N_2/100 lb kerosene

* Total amount of air required for burning kerosene will be sum of the amount of O_2 and N_2, 50.034 lbmol air/100 lb kerosene.

* Calculated composition of flue gas with stoichiometric air:

CO_2 : 7.208 lbmol/100 lb kerosene

O_2 : 0.0 (No excess air)

N_2 : 39.526 "

S : 0.003125 "

H_2O : 3.3 "

Total : 50.034 lbmol flue gas/100 lb kerosene

or 0.5 lbmol flue gas/lb kerosene

* Total volume of flue gas at operating temperature (2200 F) and 1 atm by ideal gas law (V = nRT / P)

V = (0.5 lbmol flue gas/lb kerosene) X (0.7302 atm ft3/ /lbmol R)(2660 R) / 1 atm

= 971.887 ft3 flue gas/lb kerosene

Thus, volumetric feed rate of kerosene will be

$$\frac{0.2705 \text{ ft3 flue gas/sec}}{(971.887\text{ft3 flue gas/lb kerosene})\text{x}(7\text{lb kerosene/gal kerosene})}$$

= 3.9761 E-5 gal kerosene / sec

= 9 cm3 kerosene / min

Table 4 shows volumetric feed rate of kerosene for various amount of excess air.

Table 4. Volumetric Feed Rate of Kerosene for various Percentage of Excess Air

FIXED VALUES;

LENGTH OF CHAMBER	: 6 FT
OPERATING TEMPERATURE	: 2200 F
DENSITY OF OIL	: 7 LB/GAL
NET HEATING VALUE	: 20000 BTU/LB OIL
MAXIMUM FLOW RATE OF FLUE GAS	: 0.2705 FT3/SEC

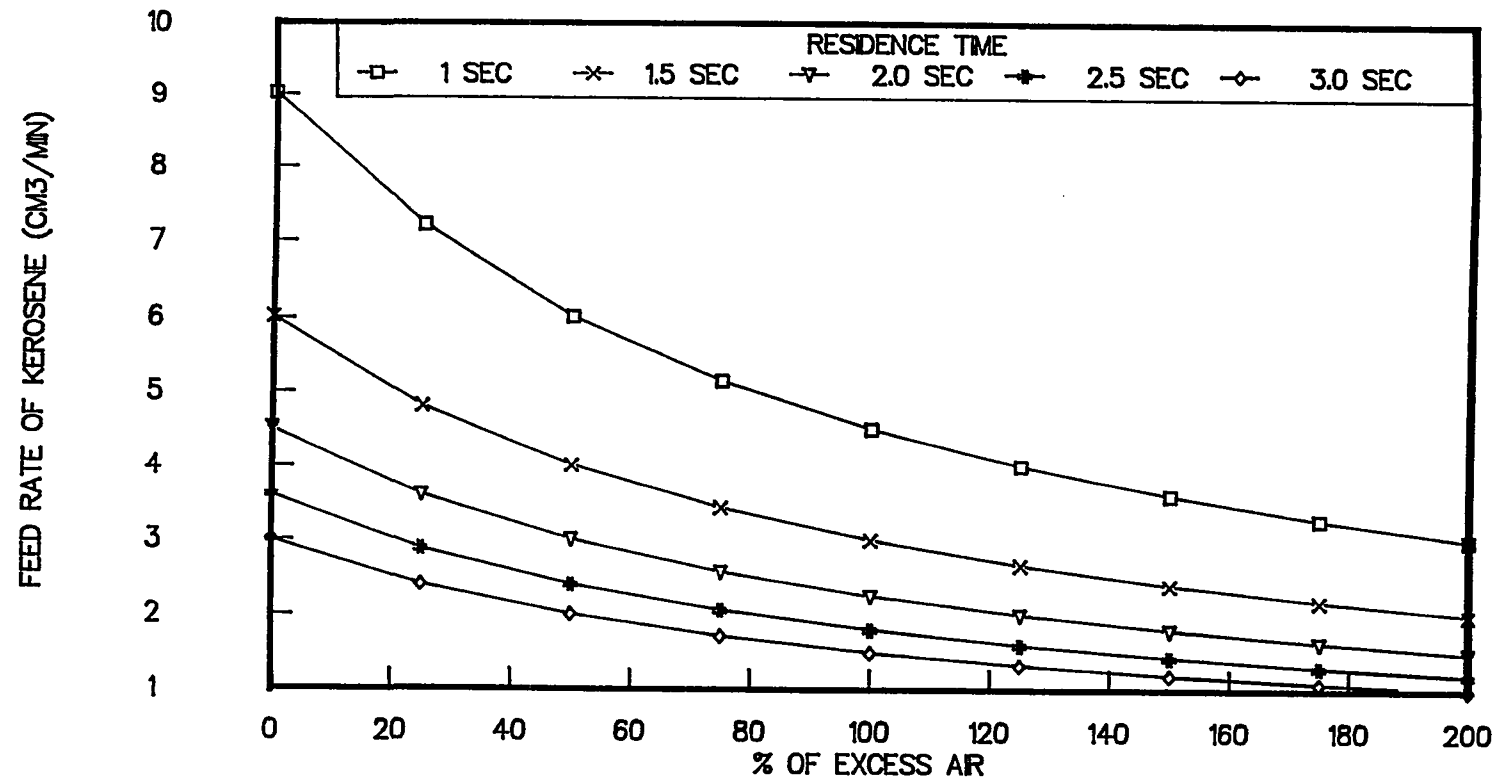
	% O2	OXYGEN LBMOL	NITROGEN LBMOL	FLUE GAS MOL/100 LB OIL	VOL OF FLUE GAS FT3 /LB OIL
0%EX O2	0.00000	10.50800	39.53010	50.03810	971.90603
25%EX O2	0.25000	13.13500	49.41263	62.54763	1214.88254
50%EX O2	0.50000	15.76200	59.29515	75.05715	1457.85904
75%EX O2	0.75000	18.38900	69.17768	87.56668	1700.83555
100%EX O2	1.00000	21.01600	79.06020	100.07620	1943.81206
125%EX O2	1.25000	23.64300	88.94273	112.58573	2186.78856
150%EX O2	1.50000	26.27000	98.82525	125.09525	2429.76507
175%EX O2	1.75000	28.89700	108.70778	137.60478	2672.74158
200%EX O2	2.00000	31.52400	118.59030	150.11430	2915.71809

Volumetric Feed Rate of Oil (Cm3/min)
for Various Excess Air and Residence Time

%O2\RES_T	1 SEC	1.5 SEC	2.0 SEC	2.5 SEC	3.0 SEC
0%EX O2	9.02947	6.01964	4.51473	3.61179	3.00982
25%EX O2	7.22357	4.81572	3.61179	2.88943	2.40786
50%EX O2	6.01964	4.01310	3.00982	2.40786	2.00655
75%EX O2	5.15970	3.43980	2.57985	2.06388	1.71990
100%EX O2	4.51473	3.00982	2.25737	1.80589	1.50491
125%EX O2	4.01310	2.67540	2.00655	1.60524	1.33770
150%EX O2	3.61179	2.40786	1.80589	1.44471	1.20393
175%EX O2	3.28344	2.18896	1.64172	1.31338	1.09448
200%EX O2	3.00982	2.00655	1.50491	1.20393	1.00327

FIGURE 10. FEED RATE OF KEROSENE (CM3/MIN)

FOR VARIOUS EXCESS AIR AND RESIDENCE TIME



5.3 Waste Oil Storage Tank

The available storage tank for oil has a volume of 4.5 ft^3, which is too large for our purposes. This would pose an explosion hazard due to the vapor-filled empty space.

The tank has been modified as follows to safely store any kind of waste oil (Figure 11). A small stainless-steel container, 6 inch-inside diameter and 6.8 inch-height, is inserted inside the large tank. The total volume of the container is 3150 cm^3. For the design flow rate, the system may thus be continuously operated for a maximum of 5.8 hours. The small container is held by three holders that are screwed on the wall of the large tank, and can be removed from the holder for cleaning or filling. A 1/2-inch pipe is welded on the bottom of the container, connected by a union, and passing through the large tank. This pipe is separated into two lines by a tee union: one line for the pump, and the other one for the drain. A length of 1/4-inch tubing is connected to the top lid which covers the container without welding. Waste oil will overflow if vapor pressure of the oil is high by being heated up. The large tank will be used for protection of explosion.

Figure 11. Modified Waste-Oil Storage Tank

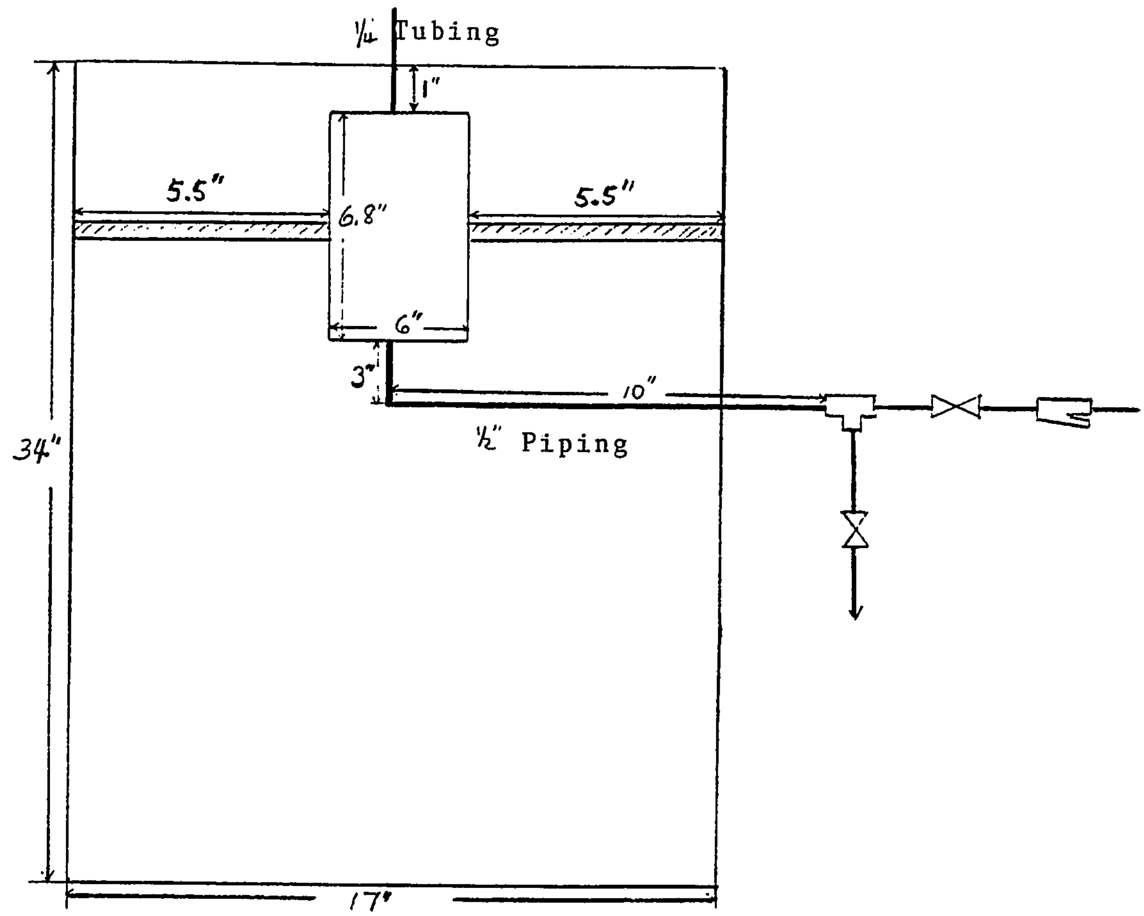


Figure 11. Modified Waste-Oil Storage Tank

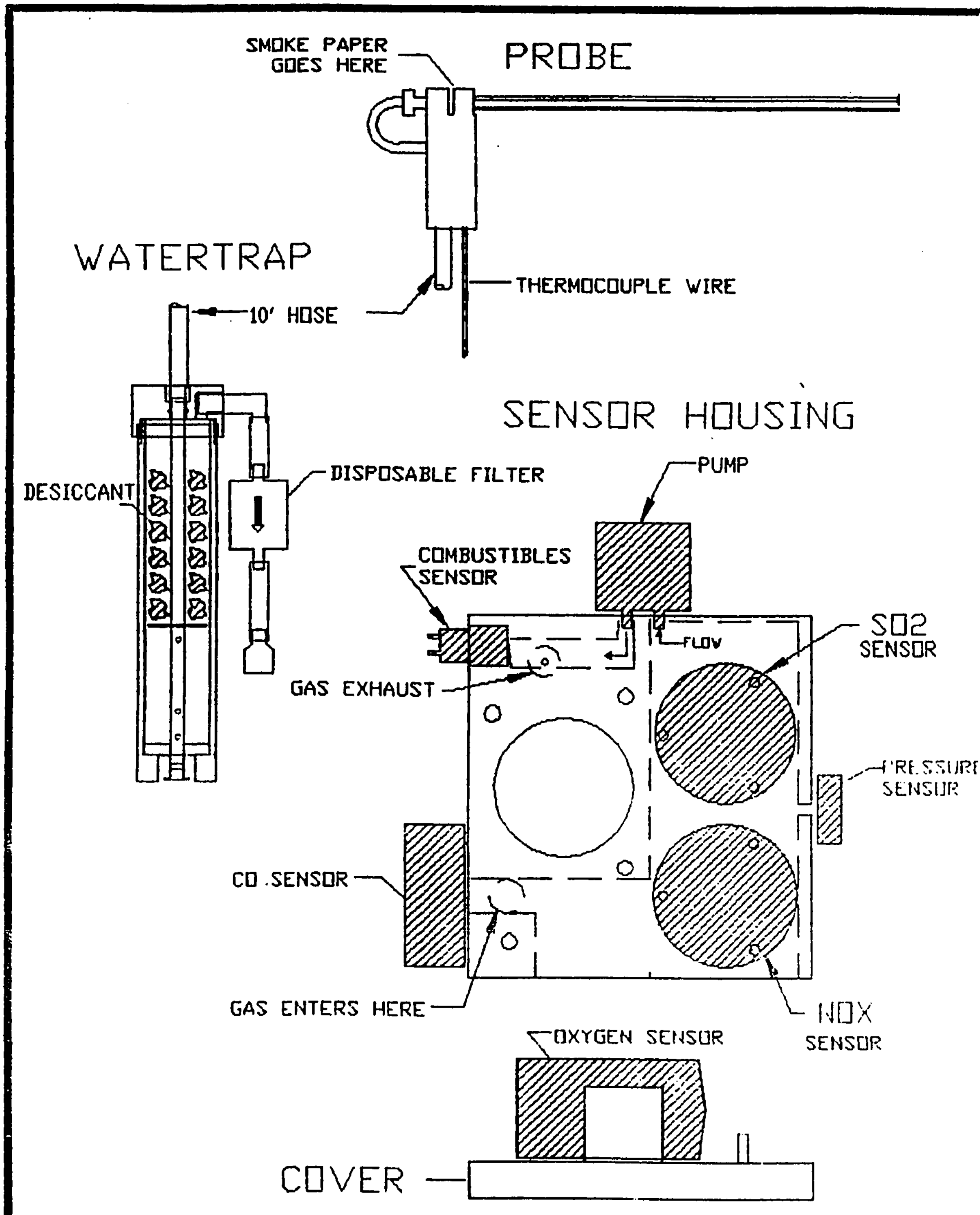
5.4 Burner and Forced Air Fan

At the time of this writing, the design of the burner with the fan was not yet available from the donor COEN company.

5.5 Emission Analyzer [16,17]

Flue gases to be monitored include oxides of nitrogen(NOx), carbon monoxide(CO), sulfur dioxide(SO2), and oxygen(O2). Ideally, separate specialized sensors should be used for each to allow most accurate measurement of trace species. At the present time, one emission analyzer (Model 2000 manufactured by Energy Efficiency System, Inc.) is used; its advantages are low cost, compactness (18"X13"X6" Aluminum carrying case with lock), and ease of use. A disadvantage is that the gas sensors (electrochemical cells) should be replaced every one or two years, depending on use. This analyzer consists of a probe, a water trap with desiccant, sensors for measuring temperature, pressure, and gas concentrations, and an RS-232 serial port for communication with a computer. The analyzer measures two temperatures (stack and ambient), five different flue gas concentrations (NOx, CO, O2, SO2, and combustibles), draft,

Figure 12. Flow Description of Flue Gases and Sensors in the Emission Analyzer



Source: Energy Efficiency System, Inc., Instruction Manual of Combustion Analyzer Model 2000, October, 1989 and smoke.

During operation of the incinerator, the 13-inch long inconel probe, which can withstand temperatures up to 2000 F, is inserted into a 3/8-inch drilled hole in the wall of the stack (Figure 12). The probe handle is designed to hold the smoke paper for the smoke test. Smoke density is measured by comparing the discoloration of the smoke paper with a standard chart provided by the manufacturer. The stack gas temperature is monitored by an inconel sheathed type K thermocouple wire inside the tube. A small pump located inside the analyzer draws a sample of the emissions through a 10-ft long braided latex hose into the water trap, which consists of a clear plastic cylindrical assembly and a disposable filter. The bottom compartment of the assembly is used to collect the condensate accumulating in the hose, and the upper compartment may be empty or filled with a desiccant to remove any additional moisture present in the emissions in order to avoid any condensation on the sensor surfaces. The emissions that exit the water trap assembly pass through the disposable fiberglass filter to trap particles of soot and fly ash that may be traveling with the emissions. It is possible to operate the instrument continuously for a long time if the excess moisture and particulates are removed from the gas stream by some other means.

After exiting the filter, the emissions are drawn into a plastic cavity sensor housing, where all the sensors are mounted for convenience and easy access, to reduce the pressure fluctuations caused by the action of the pump. The emissions pass first through the CO sensor. CO gas diffuses through a tiny hole on the face of a sealed electrochemical cell, containing three platinum electrodes and an electrolyte, and reacts with O2 present inside the cell to form CO2. The reaction produces an electric current proportional to the concentration of the gas. (It is possible to saturate the sensor by exposing it to concentrations in excess of 10000 ppm.) The emissions next pass through the O2 sensor, a two electrode electrochemical cell. An electric current is produced as O2 diffuses through a tiny hole and reacts with the lead cathode in the cell. The cell is exhausted when all the lead is consumed.

There are small openings for the pressure sensor and for the NOx and SO2 sensors. The pressure sensor, a highly sensitive and piezoresistive sensor intended for pressures from +10" to -40" of water, is located on the right hand side of the sensor housing to monitor stack draft. During a draft measurement, the pump will stop to avoid additional erroneous pressure drops due to flow resistance. NOx (NO and a very small cross sensitivity to NO2) is monitored by an electrochemical cell similar to the CO sensor, with the important exception that it needs a constant bias voltage. The SO2 sensor is an electrochemical cell also similar to the CO sensors. The pump discharges the gases into the area where the combustibles sensor is located. Molecules of combustible gas are absorbed on the surface of the sensor, a semiconductor-type sensor, and change its electrical resistance.

The instrument can store up to ninety-nine different test results in its memory. The description of the instrument's storage functions are in the instruction manual [16]. The instrument's RS-232 port is used in this work to communicate with the computer and to record emissions analyses simultaneously with the flow and temperature measurements. An RS-232 port and communication program (Personal Computer Software-ENERCOMP 2000) was installed on the computer, and the RS-232 port on the instrument was connected using a male 25-pin D type connector. Successful communication requires a common language between the two machines, such that speed of transmission and data format are the same. The values listed below are used.

Speed : 1200 Baud

Start Bits: 1

Data Bits : 8

Stop Bits : 1

Parity : None

Tests (performed without incineration occurring) of the communication system, and data acquisition and storage are described in Chapter 8.

CHAPTER 6. FLOW AND TEMPERATURE MEASUREMENT

6.1 Flow Measurement

6.1.1 Waste Oil

An inexpensive flow meter that can measure a low flow rate of oil (9 Cm3/min or less) and produce 4 - 20 mA output signals for the data acquisition system was difficult to find. A turbine flowmeter was considered, but the minimum flow rate measurable is 26 cm3/min. Thus, a positive displacement pump system (pump drive, pump head, and tubing) manufactured by Cole-Parmer is used both to pump the waste oil and to measure its flow rate. Since the pump drive does not produce any output signal, the data acquisition system can not be used to store information on flow rate. Instead, the speed controller on the pump drive will be calibrated for different waste oils before starting the incineration system, and this information must be manually entered in the log for each experiment.

6.1.2 Atomizing Air

The flow rate of atomizing air (compressed air) is determined by measuring the differential pressure across an orifice union in the atomizing air line using a differential pressure transmitter (DPT). The pressure drop can be estimated if the mass flow rate is known [13,18]. The required orifice diameter will be calculated from the capacity of the differential pressure transmitter and the proposed mass flow rate of atomizing air. Detailed calculations to estimate the orifice diameter are shown in Appendix A. The mass flow rate of atomizing air will be approximately 15 - 50% (by mass) of the liquid waste flow rate. Since the proposed liquid waste flow is 9 cm3/min, which is, (9 cm3/min)x(1 gal/3785 cm3)x(7 lb/1 gal)=0.0167 lb/min ,or 1 lb/hr, the proposed flow rate of atomizing air is 0.15 to 0.5 lb/hr (volumetric flow rate is 2 to 6.7 ft3/hr). A differential pressure transmitter, measuring from 0 - 200 inH2O, is installed to measure the differential pressure. Table 5 shows the computed pressure drops for various orifice diameters. For this application, the optimal orifice diameter is 0.035 inch. The orifice can be tested by measuring the actual compressed air flow rate using a wet test meter and voltage signals from the DPT. The actual orifice used will be calibrated in this way.

Table 5. Estimation of Orifice Diameter for the Atomizing Air Line

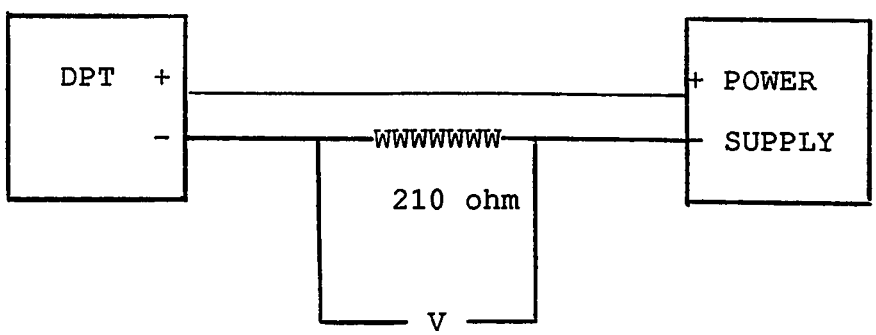
M(LB/SEC)	1.390E-04	Q(FT3/HR):6.654E+00 :MAXIMUM			
Co	7.500E-01	1.996E+00 :30% OF MAX			
Y	1.000E+00				
gc	3.217E+01				
d(LB/FT3)	7.520E-02				
Dp(IN)	6.220E-01				
Do(IN)	1.000E-02	1.500E-02	2.000E-02	2.500E-02	3.000E-02
b(Do/Dp)	1.608E-02	2.412E-02	3.215E-02	4.019E-02	4.823E-02
So(FT2)	5.454E-07	1.227E-06	2.182E-06	3.409E-06	4.909E-06
delP(PSI)	1.657E+02	3.273E+01	1.036E+01	4.242E+00	2.046E+00
del(inH2O)	4.590E+03	9.067E+02	2.869E+02	1.175E+02	5.667E+01
Do(IN)	3.500E-02	4.000E-02	4.500E-02	5.000E-02	5.500E-02
b(Do/Dp)	5.627E-02	6.431E-02	7.235E-02	8.039E-02	8.842E-02
So(FT2)	6.681E-06	8.727E-06	1.104E-05	1.364E-05	1.650E-05
delP(PSI)	1.104E+00	6.473E-01	4.041E-01	2.651E-01	1.811E-01
del(inH2O)	3.059E+01	1.793E+01	1.119E+01	7.344E+00	5.016E+00

Volumetric Flow rate of Atomizing Air Following Various Differential Pressure and Orifice Diameter Co=0.75

Do(IN)	3.000E-02	3.300E-02	3.500E-02	3.800E-02	4.000E-02
So(FT2)	4.909E-06	5.940E-06	6.681E-06	7.876E-06	8.727E-06
Dp(IN)	6.220E-01	6.220E-01	6.220E-01	6.220E-01	6.220E-01
b(Do/Dp)	4.823E-02	5.305E-02	5.627E-02	6.109E-02	6.431E-02
Co	7.500E-01	7.500E-01	7.500E-01	7.500E-01	7.500E-01

delP vs Do	3.000E-02	3.300E-02	3.500E-02	3.800E-02	4.000E-02
1.000E-01	1.471E+00	1.780E+00	2.002E+00	2.360E+00	2.616E+00
2.000E-01	2.081E+00	2.518E+00	2.832E+00	3.338E+00	3.699E+00
3.000E-01	2.548E+00	3.083E+00	3.468E+00	4.088E+00	4.530E+00
4.000E-01	2.942E+00	3.560E+00	4.005E+00	4.721E+00	5.231E+00
5.000E-01	3.290E+00	3.981E+00	4.478E+00	5.278E+00	5.848E+00
6.000E-01	3.604E+00	4.361E+00	4.905E+00	5.782E+00	6.407E+00
7.000E-01	3.892E+00	4.710E+00	5.298E+00	6.245E+00	6.920E+00
8.000E-01	4.161E+00	5.035E+00	5.664E+00	6.676E+00	7.398E+00
9.000E-01	4.414E+00	5.341E+00	6.007E+00	7.081E+00	7.847E+00
1.000E+00	4.652E+00	5.629E+00	6.332E+00	7.465E+00	8.271E+00

The transmitter requires an external power supply delivering 24 VDC with a minimum current capability of 40 milliamps to power the control loop containing the differential pressure transmitter. The 4 - 20 mA output signal generated by the differential pressure transmitter is sent to a transformer terminal strip to convert to a voltage signal (0 - 5 V) by installing a 210 ohm resistor, as shown in the following simple diagram of the connection of the power supply, transmitter, and receiver load resistance.



Vmin - Vmax (0-5 V)

Note : Receiver may be in the transmitter with + or - leg of control loop

The output voltage signal from the DPT goes to the data acquisition system to be stored in the computer. Calibration information for flow measurements is given in Chapter 8.

6.1.3 Natural Gas

The method of flow rate measurement for natural gas is the same as that for atomizing air. However, the differential pressure transmitter (DPT) used to measure the differential pressure across the orifice union, and the optimal diameter of the orifice tap, are different from those used for atomizing air. The DPT used (Rosemount Co.) can measure differential pressure from 0 - 175 inH2O and produce 4 - 20mA current output signal. The optimum orifice diameter is determined by the same calculation method as was used for atomizing air. The proposed maximum flow rate of natural gas is calculated as follows:

Heat capacity of burner: 20,000 Btu/hr

Net heating value of gas (CH_4): 21,520 Btu/LBCH4

Maximum mass flow rate of gas = Heat capacity of burner/ Net heating value of gas

= 20,000/21,520

= 0.9294 LbCH4/hr

Maximum volumetric flow rate is calculated by ideal gas law.

$V_{CH4} = nRT/P$

n = (0.9294 LbCH4/hr)/(16 LbCH4/1Lbmol)*(453.5 gmol/1Lbmol)

= 26.34 gmolCH4/hr

$R = 82.05$ Cm3 atm /gmol k

$T = 293$ k

$P = 1$ atm

$V_{CH4} = 22.36$ Ft3/hr

The maximum volumetric flow rate of natural gas is 22.36 Ft3/hr. The computed pressure drop for various orifice diameters is shown in Table 6. In this application, the optimal diameter of the orifice plate is 0.055 inch.

Table 6. Estimation of Orifice Diameter for the Natural Gas Line

M(LB/SEC)	2.582E-04	Q(FT3/HR):	2.075E+01	:MAXIMUM
Co	7.500E-01		1.037E+01	:50% OF MAX
Y	1.000E+00		4.149E+00	:20% OF MAX
gc	3.217E+01			
d(LB/FT3)	4.480E-02			
Dp(IN)	8.240E-01			

Do(IN)	1.000E-02	2.000E-02	3.000E-02	4.000E-02	5.000E-02
b(Do/Dp)	1.214E-02	2.427E-02	3.641E-02	4.854E-02	6.068E-02
So(FT2)	5.454E-07	2.182E-06	4.909E-06	8.727E-06	1.364E-05
delP(PSI)	9.595E+02	5.997E+01	1.185E+01	3.748E+00	1.535E+00
del(in H2O)	2.658E+04	1.661E+03	3.281E+02	1.038E+02	4.253E+01

Do(IN)	5.000E-02	5.100E-02	5.200E-02	5.300E-02	5.400E-02
b(Do/Dp)	6.068E-02	6.189E-02	6.311E-02	6.432E-02	6.553E-02
So(FT2)	1.364E-05	1.419E-05	1.475E-05	1.532E-05	1.590E-05
delP(PSI)	1.535E+00	1.418E+00	1.312E+00	1.216E+00	1.128E+00
del(in H2O)	4.253E+01	3.929E+01	3.635E+01	3.368E+01	3.126E+01

Do(IN)	5.500E-02	5.600E-02	5.700E-02	5.800E-02	5.900E-02
b(Do/Dp)	6.675E-02	6.796E-02	6.917E-02	7.039E-02	7.160E-02
So(FT2)	1.650E-05	1.710E-05	1.772E-05	1.835E-05	1.899E-05
delP(PSI)	1.049E+00	9.757E-01	9.090E-01	8.479E-01	7.918E-01
del(in H2O)	2.905E+01	2.703E+01	2.518E+01	2.349E+01	2.193E+01

Volumetric Flow rate of Natural gas Following Various Differential Pressure and Orifice Diameter at Co=0.75

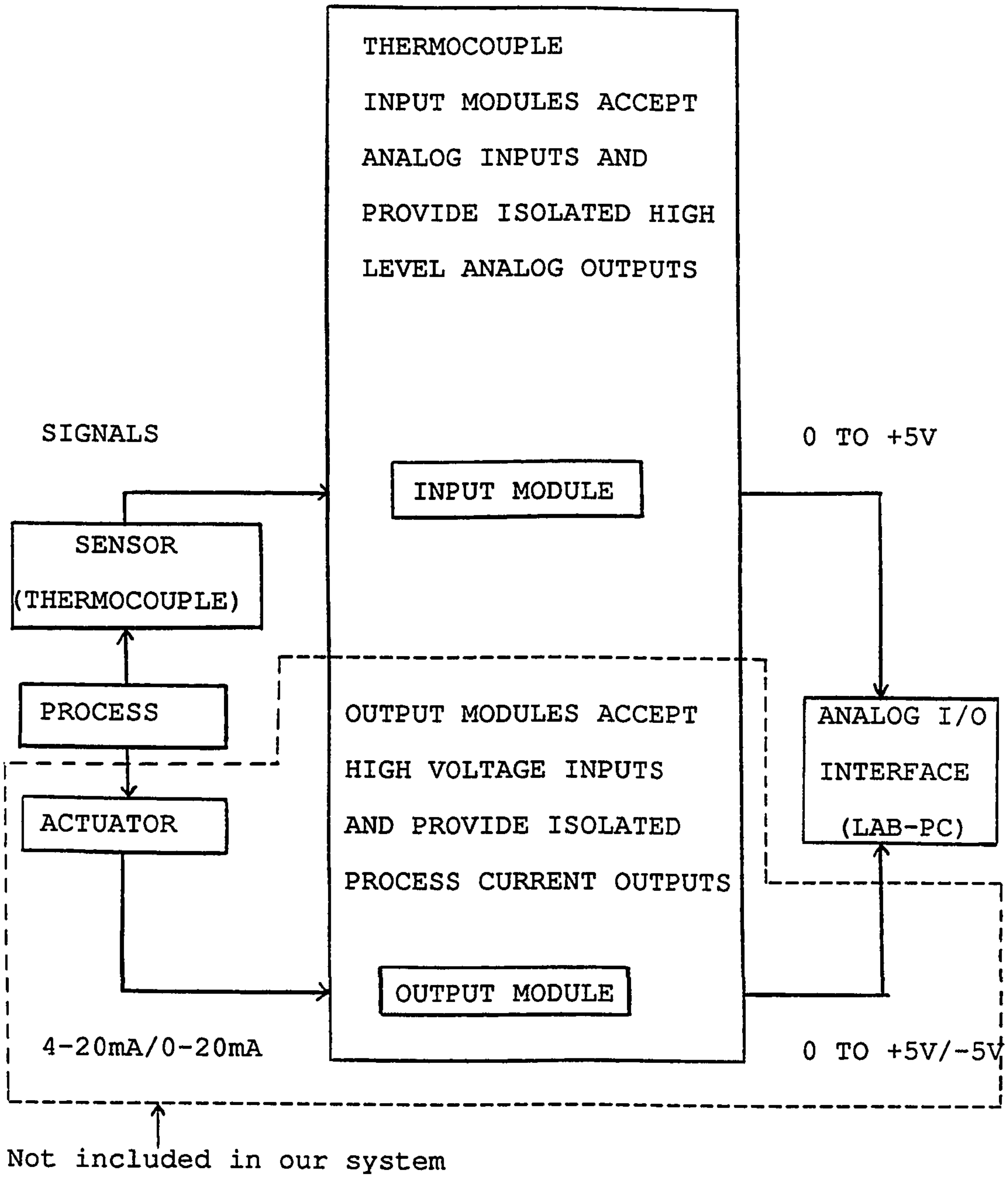
Do(IN)	5.000E-02	5.300E-02	5.500E-02	5.800E-02	6.000E-02
So(FT2)	1.364E-05	1.532E-05	1.650E-05	1.835E-05	1.963E-05
Dp(IN)	8.240E-01	8.240E-01	8.240E-01	8.240E-01	8.240E-01
b(Do/Dp)	6.068E-02	6.432E-02	6.675E-02	7.039E-02	7.282E-02
Co	7.500E-01	7.500E-01	7.500E-01	7.500E-01	7.500E-01

delP vs Do	5.000E-02	5.300E-02	5.500E-02	5.800E-02	6.000E-02
1.000E-01	5.295E+00	5.949E+00	6.407E+00	7.125E+00	7.624E+00
2.000E-01	7.488E+00	8.413E+00	9.060E+00	1.008E+01	1.078E+01
3.000E-01	9.171E+00	1.030E+01	1.110E+01	1.234E+01	1.321E+01
4.000E-01	1.059E+01	1.190E+01	1.281E+01	1.425E+01	1.525E+01
5.000E-01	1.184E+01	1.330E+01	1.433E+01	1.593E+01	1.705E+01
6.000E-01	1.297E+01	1.457E+01	1.569E+01	1.745E+01	1.868E+01
7.000E-01	1.401E+01	1.574E+01	1.695E+01	1.885E+01	2.017E+01
8.000E-01	1.498E+01	1.683E+01	1.812E+01	2.015E+01	2.157E+01
9.000E-01	1.588E+01	1.785E+01	1.922E+01	2.137E+01	2.287E+01
1.000E+00	1.674E+01	1.881E+01	2.026E+01	2.253E+01	2.411E+01

6.2 Temperature Measurement

Temperatures are measured by thermocouple probes: J-type for waste oil flowing through 1/8-inch tubing, R-type for flame temperature in the combustion chamber, and K-type for temperature profiles through the combustion chamber and for temperatures at sampling ports. 1/8-inch diameter and 12-inch long thermocouple probes are installed with round terminal blocks. Thermocouple wires are used to connect the round terminal blocks to the data acquisition system. The output voltage from the thermocouple can be converted into the actual temperature using a linearization formula. Unlike the flow measurement system, the thermocouple input module signal conditioners are used to amplify the low voltage signals, usually in the mV range, produced from the thermocouples. Figure 13 illustrates a block diagram for the temperature measurement using the data acquisition system.

FIGURE 13. Block Diagram of Temperature Measurement Using The Data Acquisition System

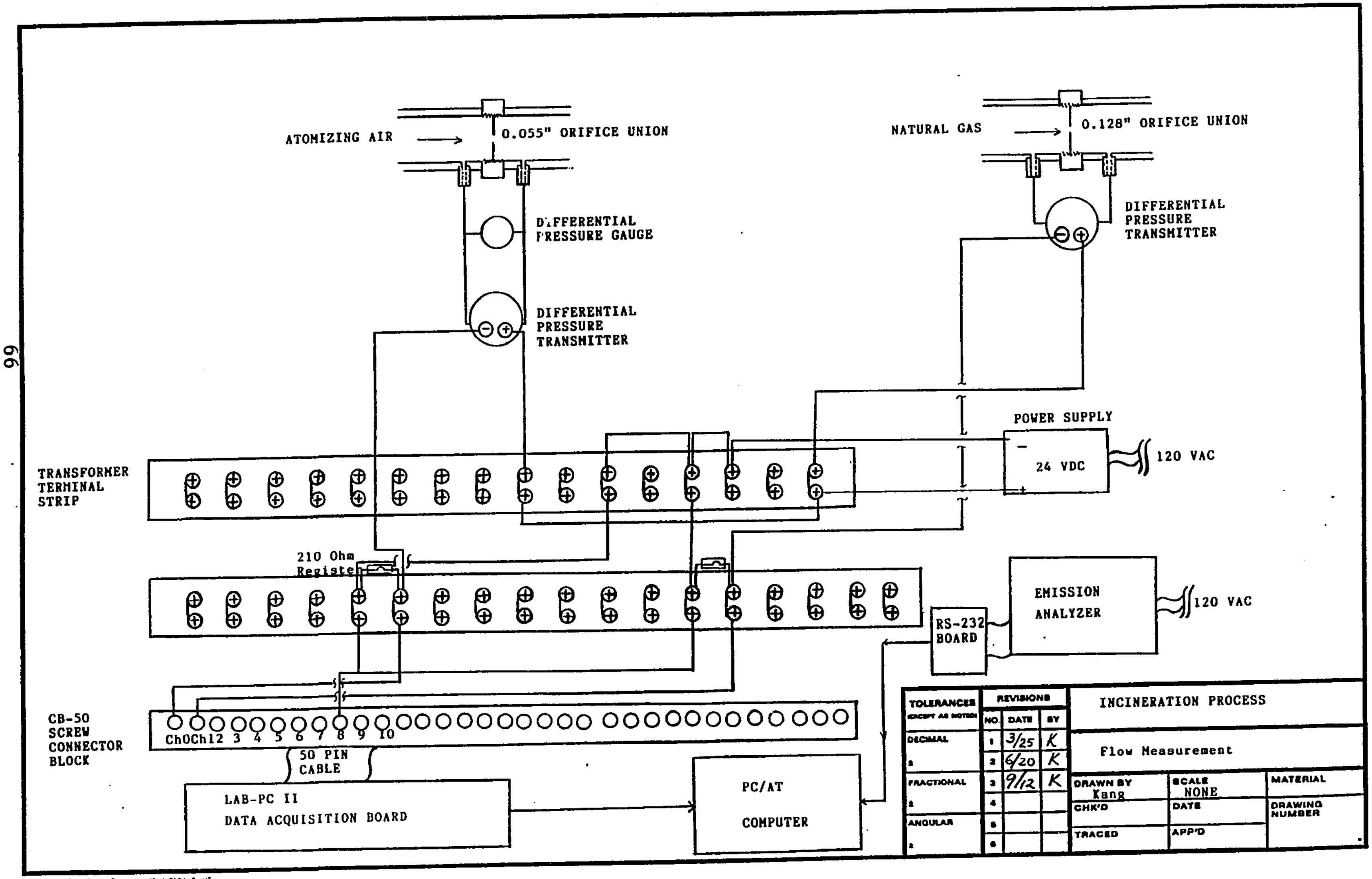


6.3 Measurement Using Data Acquisition System

In the flow measurement of atomizing air and natural gas, the output voltage signal from the DPT goes to a screw terminal block (CB-50 Block) as an analog single ended input signal. The CB-50 allows easy connection of analog/digital signals to the data acquisition board (Lab-PC Board, A/D hardware interface). The CB-50 consists of a 1 meter ribbon cable and a connector block with 50 screw terminals, corresponding to the 50-pin ribbon cable for the Lab-PC board. Connector pinout information is shown in the Lab-Pc user's manual. The single ended signal is sent to the Lab-PC board, which is installed in one of the 8-bit expansion slots in the PC/AT compatible computer. The instrumentation diagram for flow measurement is shown in Figure 14.

In the temperature measurement, the thermocouple input modules accept input signals from type J, R, and K thermocouples and generate 0 to +5V outputs. These modules incorporate a circuit design utilizing transformer-based isolation and automated surface mount manufacturing technology. This allows for long term stability and channel isolation. All modules are hard potted and identical in pinout and size (2.25"x2.25"x0.60"). They can be mixed and matched on a backplane which provides a complete signal conditioning solution and sixteen channels. Each channel has

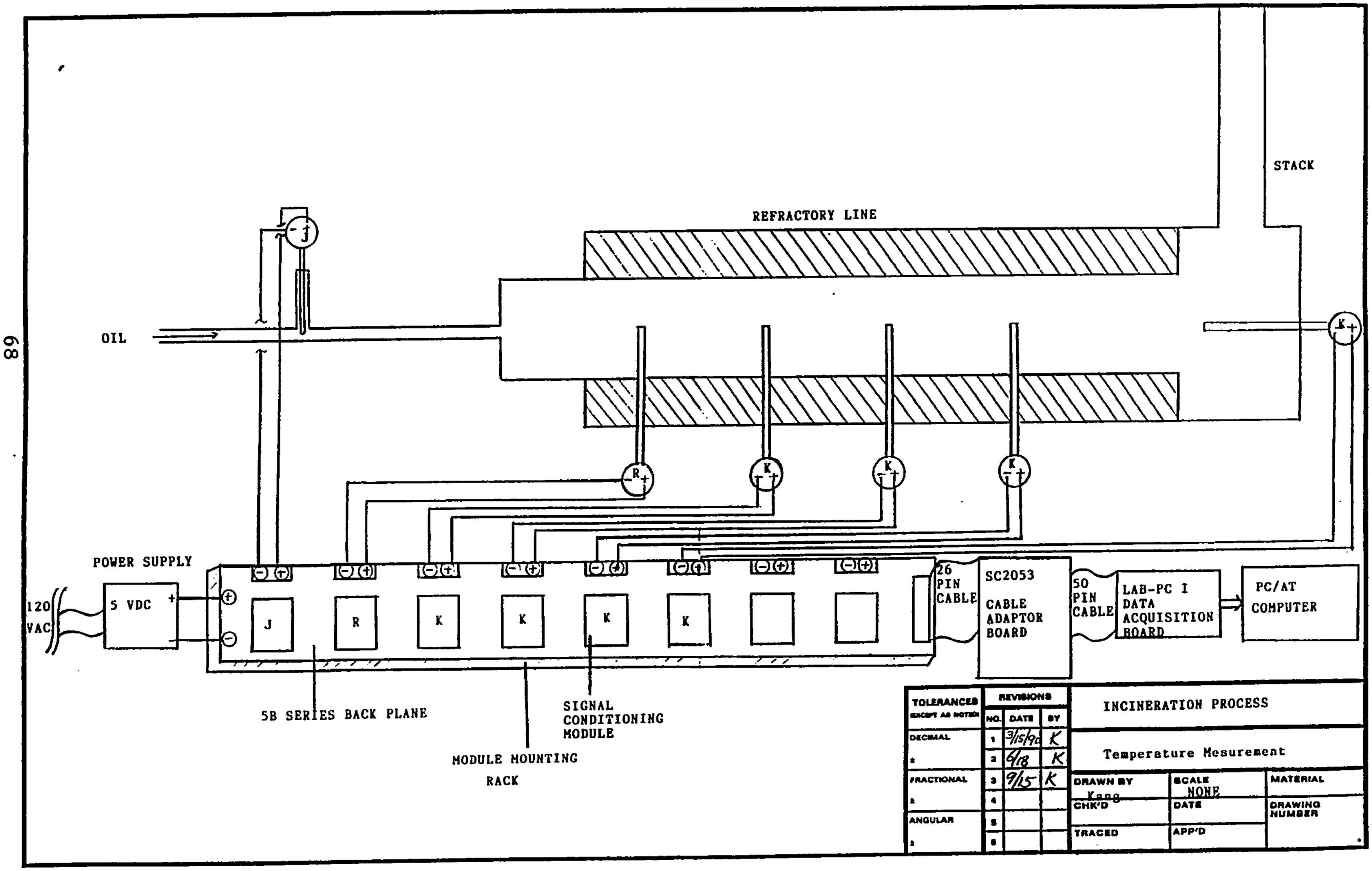
FIGURE 14. INSTRUMENTATION DIAGRAM OF FLOW MEASUREMENT



four screw terminals for field connections. A cold junction sensor is supplied on each channel to accommodate TC module. The 16-channel backplane is mounted in a 19" x 3.5" panel space, and requires an external +5V power supply. In our system, the TC modules, type J, type R, and four type K was installed at channel No 0, 1, 2, 3, 4, and 5 respectively. The output signals from the thermocouple input modules on the backplane are converted to input connector signals for a second data acquisition board (in addition to the one used for the flow measurement system) through a cable adapter board. The cable adapter board (SC-2053) is inserted between the Lab-PC board and the backplane in order to interface the signal conditioning modules to the Lab-PC board. To connect the cable adapter board to the signal conditioning module on the backplane, a 26-pin ribbon cable is used. A 50-pin ribbon cable is used to connect the cable adapter board to the data acquisition board. Actual instrumentation for temperature measurement using data acquisition system is shown in Figure 15.

The data acquisition board (Lab-PC Board) [19] is a multifunction analog, digital, and timing input/output (I/O) board for the IBM PC/XT, PC/AT, PS/2, and compatible computers. It contains a 12-bit successive-approximation analog-to-digital converter (ADC) with eight analog inputs, two 12-bit digital-to-analog converter (DACs) with voltage

FIGURE 15. INSTRUMENTATION DIAGRAM OF TEMPERATURE MEASUREMENT



analog outputs, 24 lines of transistor-transistor logic (TTL) compatible digital I/O, and three 16-bit counter/timer channels for timing I/O. The analog input range is +/-5 V for bipolar input and 0 to 10 V for unipolar input. The Lab-PC board is configured at the factory to a base I/O address of hex 260, to use direct memory access (DMA) channel 3, and to use interrupt level 5. These settings are suitable for most systems. If different hardware board is used, these settings on the Lab-PC board will need to be changed as described in the Lab-PC User Manual [19]. For example, I/O address settings in the Lab-PC boards are hex 260 for the Lab-PC I (temperature measurement) and hex 2A0 for the Lab-PC II (flow measurement). The maximum number of Lab-PC boards that can be installed in the computer is four because of the limits on the integrating capacity of the software package (Measure).

Communication between the computer and test instruments is established using the Measure software package, an add-in for Lotus 1-2-3 that controls data acquisition hardware and collects, converts, and stores data directly into a 1-2-3 spreadsheet. Analog-to-digital, digital-to-analog, and digital input/output conversions are accomplished with Measure and the Lab-PC board. The information is entered into settings sheets that can be saved and reused. Lotus 1-2-3 can be used to reduce, analyze, and present the data immediately. Procedures for adding the appropriate driver to a basic 1-2-3 driver set and starting Measure are described in the Data Acquisition Module Reference [20].

The data values returned by the data acquisition board are in raw analog-to-digital (A/D) form. The data acquisition board returns integers from 0 to 4095. In most applications, this raw A/D data (0-4095) must be converted into engineering units to be useful. First A/D data must be converted into voltage, which is same as the voltage produced by the instrument, and then the voltage is converted into the actual data (engineering units) by a linearization formula or interpolation at the voltage value. For example, the bipolar input formula for +/-5 V of analog input range is:

Volts = ([]-2048)x(voltage span/4095)

In this formula, [] represents the A/D data (0-4095) returned by the data acquisition board (Lab-PC). Voltage span is a decimal number that represents the total span of the input voltage range that has been selected, which is +5 minus (-5), or 10. For the unipolar formula,

Volts = []x(voltage span/4095)

These formulas are entered into the Measure data acquisition module using the Formula menu item. If a formula is active, the Measure data acquisition module automatically converts the raw data before placing it in the 1-2-3 spreadsheet.

In our system, the bipolar configuration settings are used for both Lab-PC boards. The conversion formula for the flow measurement, A/D data to voltage, is

VOLTS = ([ ]-2048) x (10/4095)

In order for voltage to be converted to the actual pressure drop or flow rate, the correlations for voltage to pressure drop or flow rate are applied. The correlations can be found from the experimental data in Chapter 8. For example, the correlation for the atomizing air line using 0.055-inch orifice is

FLOW RATE (ft3/hr) = 2.487x(1.732452xV-1.51884)^0.64

For the natural gas line,

FLOW RATE (ft3/hr) = 10^(0.4132log(0.2615xV-0.2298)+1.05)

Thus, the actual flow rates can be found from measured voltages using the above formulas in the spread sheet.

For the temperature measurement, the conversion formula is the same as the one for the flow measurement; however, a gain factor for the thermocouple (TC) module must be added. Calculations of the gain factor for the TC modules used in our system are shown in Appendix B. For example, the actual voltage from the type K of TC is,

VOLTAGE = (CONVERSION FORMULA FOR BIPOLAR) x (GAIN FACTOR)

CONVERSION FORMULA = ([ ]-2048) x (10/4095)

GAIN FACTOR FOR TYPE K = (54.125-(-3.553))/5 - 3.553

$$\text{VOLTAGE (V)} = \frac{\{([\ \ ]-2048) \times (10/4095)\} \times 11.5356 - 3.553}{1000}$$

Then the temperature can be computed from the voltage (above) using the polynomial correcting equation in nested form.

$$T \text{ (deg C)} = a0 + V \times (a1 + V \times (a2 + V \times (a3 + - - - - -)))))$$

The polynomial coefficients can be found by regression [21].

CHAPTER 7. OPERATING THE SYSTEM USING THE FLAME SAFEGUARD CONTROL

As a flame safeguard control system, interlocks (safety shutoff valves), limits (pressure and temperature switches, toggle switches, push buttons), and a programmable logic control unit (PLC), manufactured by G.E. Fanuc, are used to provide safe control of burner operation, including safe starting and stopping of the burner and supervision of the burner flame during operation.

Low and high-pressure limits for all feeds (atomizing air, oil, and natural gas) are set in the dual pressure limit switches. Low and high temperature single switches are installed on the oil line to limit the temperature of the heavy viscosity oil. Shutoff valves (solenoid valves) and push buttons are conditioned by "normally-open" or "normally-closed", which refers to contact states with no power flow through the relay coil. Instructions programmed into the memory of the PLC control the functioning of the interlocks for given conditions. The theory of the PLC is explained in Appendix C.

The PLC unit consists of a 16 point input terminal, a 12 point output terminal, and a hand-held programmer. The advantages of using the PLC rather than hardware control systems (relays, electrical timers and counters, or mechanical drum sequencers) are reliability, compactness, ease of maintenance, and versatility. For instance, if one more input or output devices have to be added to the system, one only needs to access the electrical wire to the input or output terminal point and to change the program in the PLC. A disadvantage of the PLC is that time is required to understand the system and programming, depending on the user's knowledge of PLC operation.

In order to program the instructions, the logical sequence, or logic chart, of how the process functions must be provided. Based on the logic chart, a ladder diagram is constructed for the desired actions of the control circuit. Elements of the ladder diagram represent contacts (normally-open and normally-closed contacts), coils, and other functional components. The next step is to develop logic programs on the real PLC using specific programming technics from the G.E. series manual. In the next section, the logic programs will be developed from the operational procedure, logic chart (Figure 16), and ladder diagram (Figure 17), and then tested by operating the system.

7.1 Standards from the National Fire Code for Incinerator Operation

Before establishing a procedure to operate the system, the following sequences are applied to the system according to the National Fire Code [22]. The system is operated semi-automatically by the PLC and the operator. The four major operation modes are described as follows: pre-firing, light-off, modulation, and shutdown.

A. Sequence of Programmed Steps in Pre-firing Operation

1. Circulate oil using the recirculating system to satisfy all interlocks where included. (Heavy oil must be heated)
2. Make sure the fuel safety shutoff valve is closed.
3. Check with flame sensor that no flame is present at the burner.
4. Start fan.
5. Admit atomizing air to main burner.
6. Satisfy atomizing air interlocks.
7. Satisfy appropriate fuel interlocks.
8. Flush out the incineration chamber with air to remove combusted or especially uncombusted gases.
   (Purging the incinerator prior to pilot gas ignition is performed to remove any uncombusted gases, which is called pre-purge.)

B. Sequence Programmed Step in Light-off Operation After Completion of Pre-firing.

10. Energize igniter.
11. Make sure main flame starts within 15 seconds.
    * If main flame starts, admit fuel to main burner.
    * If not, establish safety shutdown.
12. Shut off igniter.

C. Modulation

Modulation is accomplished manually to vary the fuel and air flows to the burner in accordance with load demand and to meet operating criteria.

D. Sequence of Programmed Step in Normal Shutdown Operation

13. Shut off fuel supply to main burner.
14. For oil:
    * Open recirculating valve.
    * Shut off atomizing air.
15. For gas, vent gas piping before safety shutoff valve to atmosphere.
16. Post-purge the incinerator after the flame is extinguished to remove any uncombusted gases which could ignite when in contact with the hot refractory wall of the

chamber.

17. After post-purge, shut down fan.

D'. Safety shutdown interlocks are provided for fail-safe operation. The following conditions will trigger a safety shutdown until the necessary corrective action is taken to assure that safe operating conditions prevail before restarting.

* Safety Interlocks for Oil Delivery System:
  1>. Under-pressure in the fuel supply at the inlet to the safety shutoff valve.
  2>. Under-temperature of Nos. 5 and 6 oils.
  3>. Loss of combustion air supply.
  4>. Loss of or failure to establish flame.
  5>. Loss of control system actuating energy, pneumatic or hydraulic valves.
  6>. Loss of, or under-pressure in, the atomizing air supply.
  7>. Loss of power supply.

* Safety Interlocks for Gas Delivery System:
  1>. Over-or under-pressure in the gas supply at the service connection.

2>. Loss of combustion air supply.

3>. Loss of, or failure to establish, flame.

4>. Loss of control system actuating energy, pneumatic or hydraulic valves.

5>. Loss of, or under-pressure in, the atomizing air supply.

6>. Loss of power supply.

The safety shutdown consists of the following:

13. Shut off fuel supply to main burner.
14. Shut off fuel supply to the igniter and interrupt spark if igniter is in operation.
15. For oil:
    * Open recirculating valve.
    * Shut off atomizing air.
16. For gas, vent gas piping before shutoff valve to atmosphere.
17. After post purge, shut down fan.
18. Manually reset the interlocks.

7.2 Operating Procedures

The overall operating procedures include both manual and automatic actions. These are described for each operating mode as follows:

Note: Specifications shown in brackets < > are performed by the PLC automatically when the operator performs the preceding instructions. A logic chart and ladder diagram for programming the specifications into the PLC are shown as figures 16 and 17.

A. Sequence of Operating Steps for Pre-firing

1. Open manual oil valve with fuel oil circulating.
   <oil limits>
2. Power oil pump on. Do not turn on the pump when natural gas only is burning.
3. Power PLC on and push RUN mode.
4. Power input and output devices on.
5. Push purge start button. (Air fan is on. After 120 seconds, "Purge Complete" indicator will be on.)
   <Start air fan>
6. Select Oil/Gas/Both switch. (Toggle switches)
   ("Oil" switch is for burning light oil.
   "Gas" switch is for burning natural gas only.
   "Oil and Gas" switch is for burning heavy oil.)

7. Open manual atomizing air (ATM air) valve, unless "Gas" switch was selected.

   <ATM air limits>

   <Admit ATM air to burner>

B. Sequence of Light-off Operating Steps Following Pre-firing

8. Open manual natural gas valve.

   ("Gas Limits" indicator is on.)

   <Gas limits>

9. Push pilot start button.

   ("Pilot On" indicator is on.)

   <Pilot on>

   Fifteen seconds after pushing the pilot start button, "Pilot On" indicator will be on. Otherwise, two indicators ("Purge Complete" and "Gas Limits") will be off. In order to reignite:

   * Close The ATM Air manual valve.
   * Open the manual vent valve on the gas line.
   * Close the manual gas valve.
   * Push the burn stop button.
   * Then go back to step 5. (Push the purge start button.)

10. Push gas start button if gas is selected in step 6.

    ("Gas On" indicator is on.)

<Admit main gas>

11.Push oil start button if oil is selected in step 6.

("Oil On" indicator is on.)

<Admit main oil>

C. Modulation

Adjust the speed controller on the fuel oil pump to vary fuel oil flow rate or the speed controller on the air fan to vary combustion air flow rate.

D. Sequence of Shutdown Operating Steps

1. Close the oil and gas supply manual valves.

   (All indicators are off except "Purge Complete".)

2. Open the manual vent gas valve.

3. Close the ATM air supply valve.

4. Push the burn stop button.

   ("Purge Complete" indicator is off. After two minutes, the air fan will be off.)

FIGURE 16. LOGIC CHART

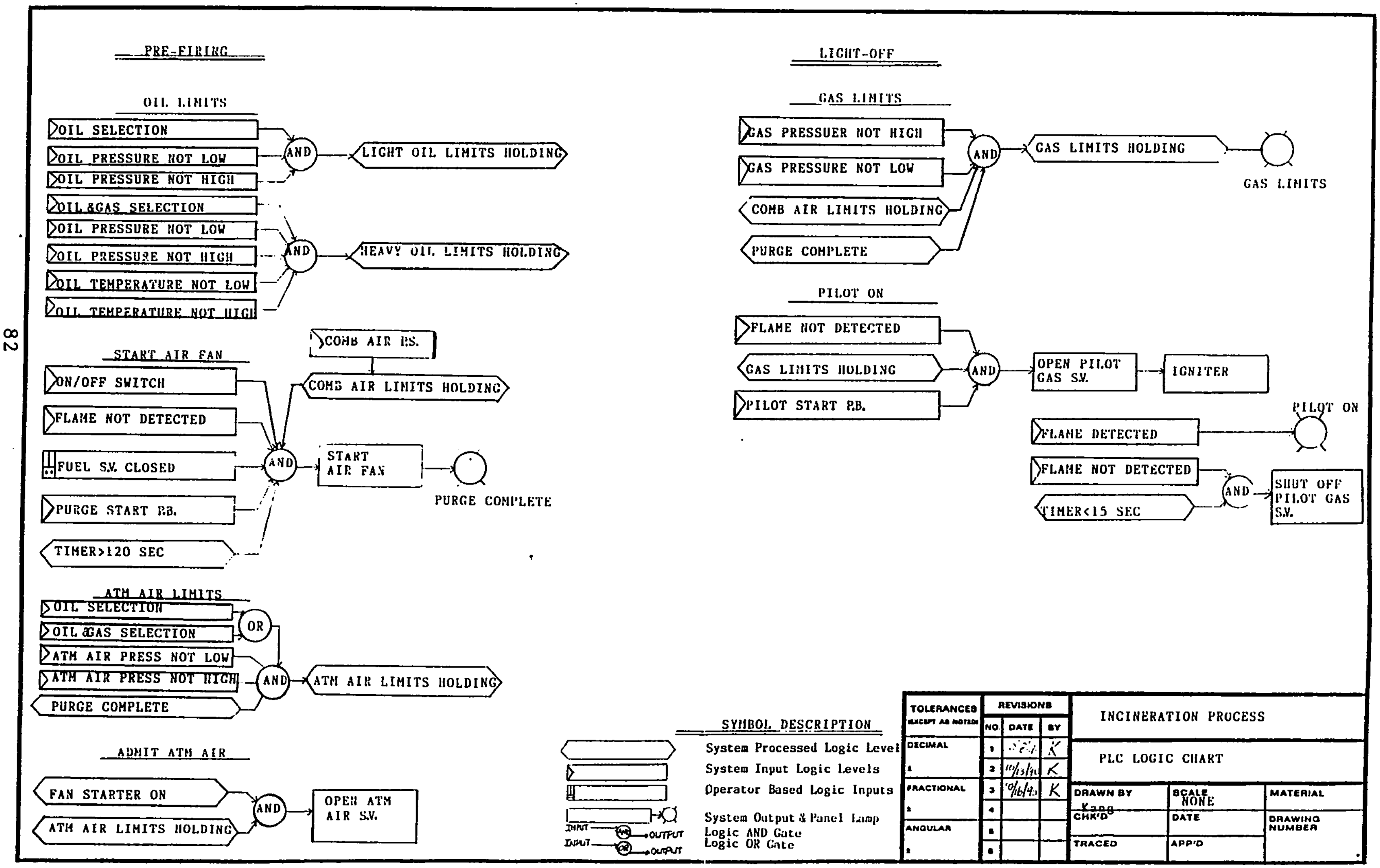
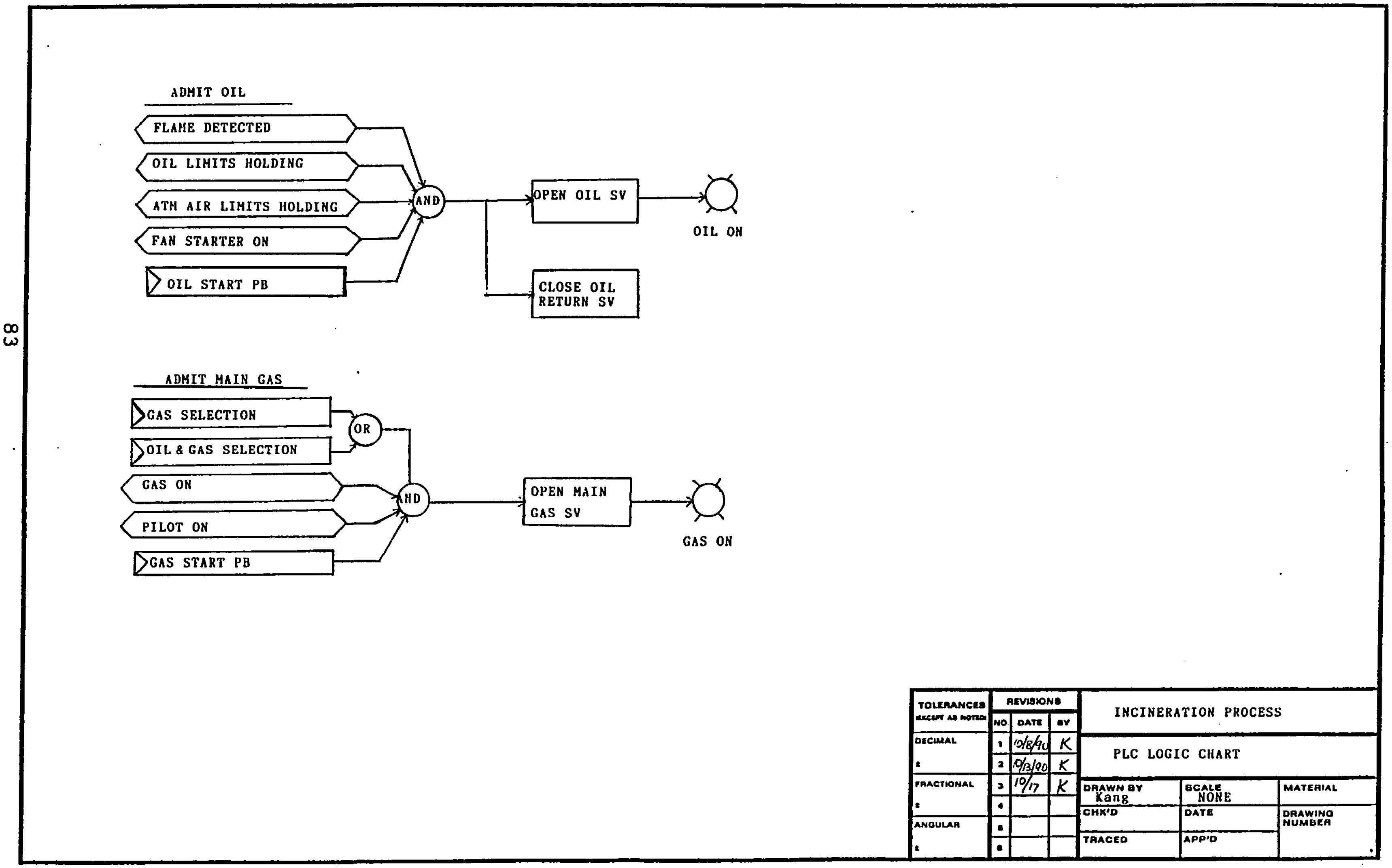


FIGURE 16. LOGIC CHART

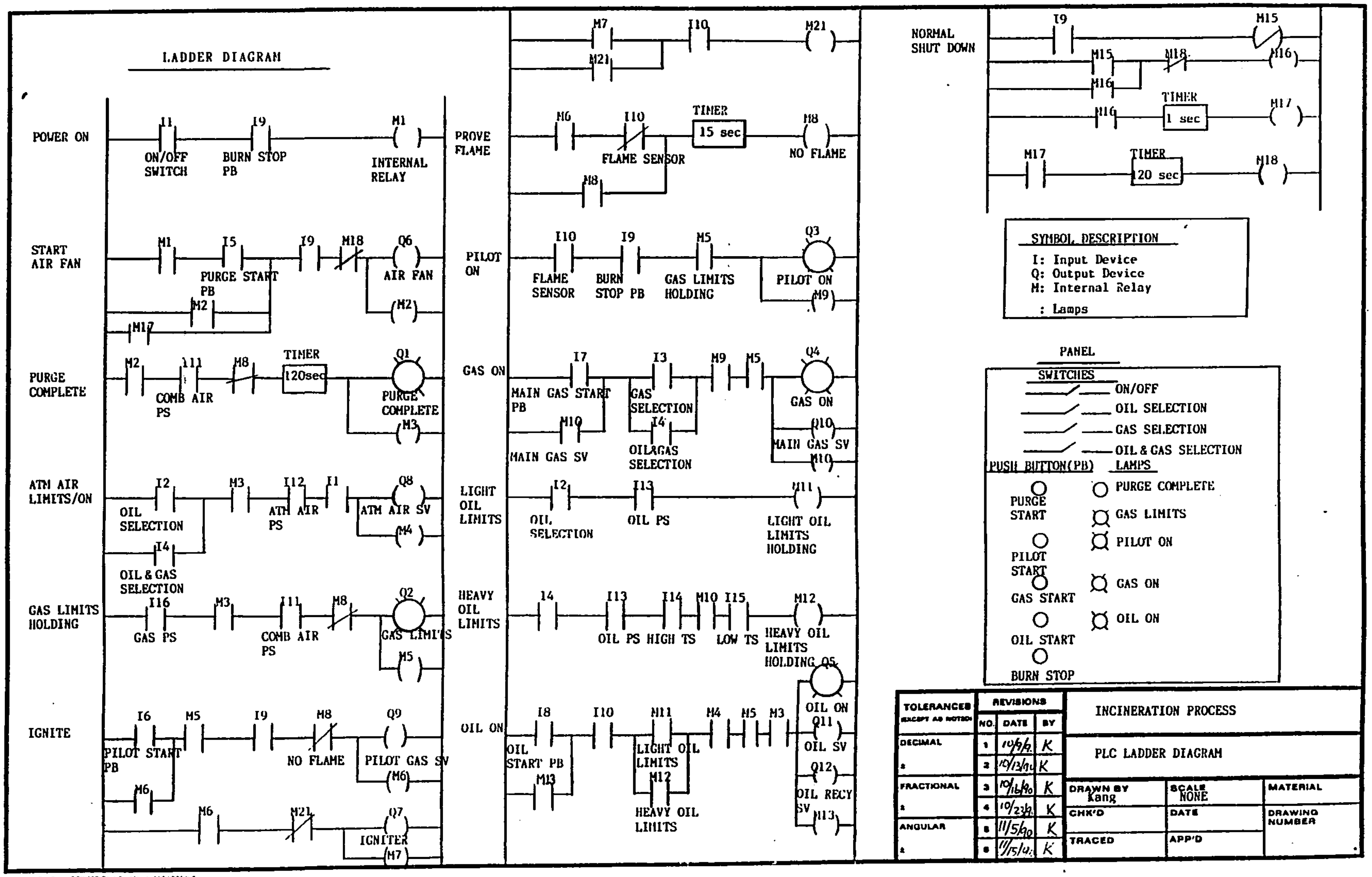


7.3 Description of PLC Ladder Diagram

The PLC ladder diagram is a representation of the control system for the safe operation of the incineration process, including start-up, normal shutdown, and emergency shutdown (flame safeguard). The vertical lines on either side of the diagram (Figure 17) represent power buses, with current flowing from left to right. The horizontal lines (rungs) contain the programmable logic for controlling the process. Normally open or closed contacts, which can represent actual input devices (ie. switches) or internal contacts, determine whether power is transferred to the output devices at the right power bus. Output devices can be actual devices such as solenoid valves, indicator lights, or internal relay coils which are programmable parameters which can be utilized as needed. In the diagram, logic elements are identified by a number preceded by a letter which indicates its function. An "I" preceding a number represents a real input device. A "Q" represents a real output device. A "M" denotes a logic parameter which is programmable.

The first rung represents system power-on. When the normally-open (N.O.) On/Off switch is closed, power is passed to the stop switch which is normally-closed (N.C.) and continue to the internal relay (I.R.) coil M1, energizing it.

FIGURE 17. LADDER DIAGRAM



Rung two logic operates the combustion air fan. N.O. contact M1 closes as internal relay M1 is energized, passing power to I5, the Purge Start push button. When this push button (P.B.) is pressed, power passes through the N.C. Stop P.B. to Q6 which turns on the fan, and I.R. M2 which closes contact M2 which keeps power flowing until the Stop P.B. is pressed breaking power flow. Contact M17 is for post-purge and becomes activated when the Stop button is pushed.

Rung three represents purge complete logic. M2 contact is closed in Rung 2 passing power to the N.O. Combustion Air pressure switch (P.S.), which closes when pressure is adequate, to a timer, which after 120 seconds passes power through the N.C. M8 contact to the Purge Complete indicator light and I.R. coil M3.

In Rung four, atomizing air limits are monitored. Power is passed through the Oil Selection switch or Oil & Gas Selection switch, determined by the operator, through the purge complete contact M3, to the ATM Air P.S. which closes when pressure is adequate through the On/Off switch to the ATM Air solenoid valve (S.V.) and I.R. coil M4.

In the fifth rung, power is supplied to the Gas Limits Lamp and I.R. coil M5 when the Natural Gas P.S. closes (adequate pressure).

The sixth rung controls the flame igniter. If gas limits are holding and no flame is detected, the Pilot Gas S.V.

will open when the Pilot Start P.B. is pressed. I.R. coil M6 is also energized, closing contact M6 in Rung 7, which sends power to the igniter and I.R. M7.

In Rung 8, the closed M7 contact passes power to the Flame Sensor contact which is represented as a N.C. contact. If no flame is detected, the contact remains closed, passing power to a timer of 15 seconds. If no flame is detected in 15 seconds, power is passed to I.R. coil M8. If M8 is energized, the N.C. contact M8 in Rungs 3, 5, and 6 is opened, causing a loss of purge complete, ATM air limits, and natural gas limits, causing the star-up sequence to stop. The start-up must be started again from the beginning. If a flame is detected, however, the N.O. Flame Sensor contact I10 in Rung 9 closes which passes power the Pilot-On indicator and I.R. M9.

Rung 10 controls the main gas line. When power is passed through the Gas Start P.B. and either the Gas Selection switch or the Oil & Gas Selection switch and through contacts M5 and M9, which were previously energized, the Main Gas S.V. is opened and the Gas-On indicator is lit. I.R. coil M10 is also energized.

Rung 11 contains logic for the light oil limits. If the Oil Selection switch is closed and the oil pressure is adequate, power is passed through the N.O. Oil P.S. to I.R. M11.

In Rung 12, heavy-oil limits are determined. If the Gas and Oil switch (I4) is selected and the N.O. Oil P.S. closes, power is passed to the Oil Temperature switches. The High Temperature Switch will remain closed as long as the oil temperature is below the high set point. The Low Temperature Switch, which is N.O., will close when the oil temperature is above the low set point. If these conditions are met, power will be passed to I.R. M12.

Rung 13 controls the main oil line. When the Oil Start P.B. is pressed, power is passed to a N.O. contact associated with the flame sensor. If a flame is detected, the contact closes, passing power through three contacts associated with oil and air limits and purge complete. This will energize the Oil-On indicator and I.R. M13, open the Main Oil S.V., and close the Oil Recycle S.V..

Rungs 14-17 control post-purge after burning has stopped. I.R. 15 energizes when it does not receive power flow, i.e. when the Stop P.B. is pressed, contact M15 closes in Rung 15 energizing I.R. M16. Contact M16 then energizes I.R. M17 after one second delay. This keeps the fan operating in Rung 2 for 120 seconds, completing the post purge.

7.4 Logic Program in the PLC

The ladder logic program for the incineration process is established following the User's Manual [24] which describes how to install and use the Hand-Held Programmer to create the program.

```
0001 LD I1
0002 AND I9
0003 OUT M1
0004 LD M1
0005 AND I5
0006 OR M2
0007 OR M17
0008 AND I9
0009 AND NOT M18
0010 OUT Q38
0011 OUT M2
0012 LD M2
0013 AND I11
0014 AND NOT M8
0015 FUNC 10 {P1:10, P2:1200, p3:R1}
0016 OUT Q33
0017 OUT M3
0018 LD I2
```

```
0019 OR I4
0020 AND M3
0021 AND I12
0022 AND I1
0023 OUT Q40
0024 OUT M4
0025 LD I16
0026 AND M3
0027 AND I11
0028 AND NOT M8
0029 OUT Q34
0030 OUT M5
0031 LD I6
0032 OR M6
0033 AND M5
0034 AND I9
0035 AND NOT M8
0036 OUT Q41
0037 OUT M6
0038 LD M6
0039 AND NOT M21
0040 OUT Q39
0041 OUT M7
0042 LD M7
0043 OR M21
```

```
0044 AND I10
0045 OUT M21
0046 LD M6
0047 AND NOT I10
0048 OR M8
0049 FUNC 10 {P1:10, P2:150, P3:R4}
0050 OUT M8
0051 LD I10
0052 AND I9
0053 AND M5
0054 OUT Q35
0055 OUT M9
0056 LD I7
0057 OR M10
0058 LD I3
0059 OR I4
0060 AND BLK
0061 AND M9
0062 AND M5
0063 OUT Q36
0064 OUT Q42
0065 OUT M10
0066 LD I2
0067 AND I13
0068 OUT M11
```

```
0069 LD I4
0070 AND I13
0071 AND I14
0072 AND M10
0073 AND I15
0074 OUT M12
0075 LD I8
0076 OR M13
0077 LD M11
0078 OR M12
0079 AND BLK
0080 AND I10
0081 AND M4
0082 AND M5
0083 AND M3
0084 OUT Q37
0085 OUT Q43
0086 OUT Q44
0087 OUT M13
0088 LD I9
0089 OUT NOT M15
0090 LD M15
0091 OR M16
0092 AND NOT M18
0093 OUT M16
```

```
0094 LD M16
0095 FUNC 10 {P1:10, P2:10, P3:R7}
0096 OUT M17
0097 LD M17
0098 FUNC 10 {P1:10, P2:1200, P3:R10}
0099 OUT M18
```

CHAPTER 8. TEST OF MEASUREMENT, DATA ACQUISITION, AND FLAME SAFEGUARD SYSTEMS

8.1 Calibration of Oil Pump

The oil pump unit was calibrated by running water through the oil line, including pressure and temperature switches and solenoid valves from the oil container in the tank. Flow rates of water for various rpm of the speed controller on the pump drive were recorded for two pump heads (No 13 and No 14).

Table 7. Calibration of Pump Drive Using Water at 25°C

RPM of Speed Controller	Flow Rate of Water (Cm3/min)	
	No.13	No.14
1000	5.9	19.2
900	5.3	17.2
800	4.7	15.2
700	4.1	13.2
600	3.5	11.2
500	2.9	9.2
400	2.3	7.2
300	1.7	5.2
200	1.1	3.2
100	0.5	1.2

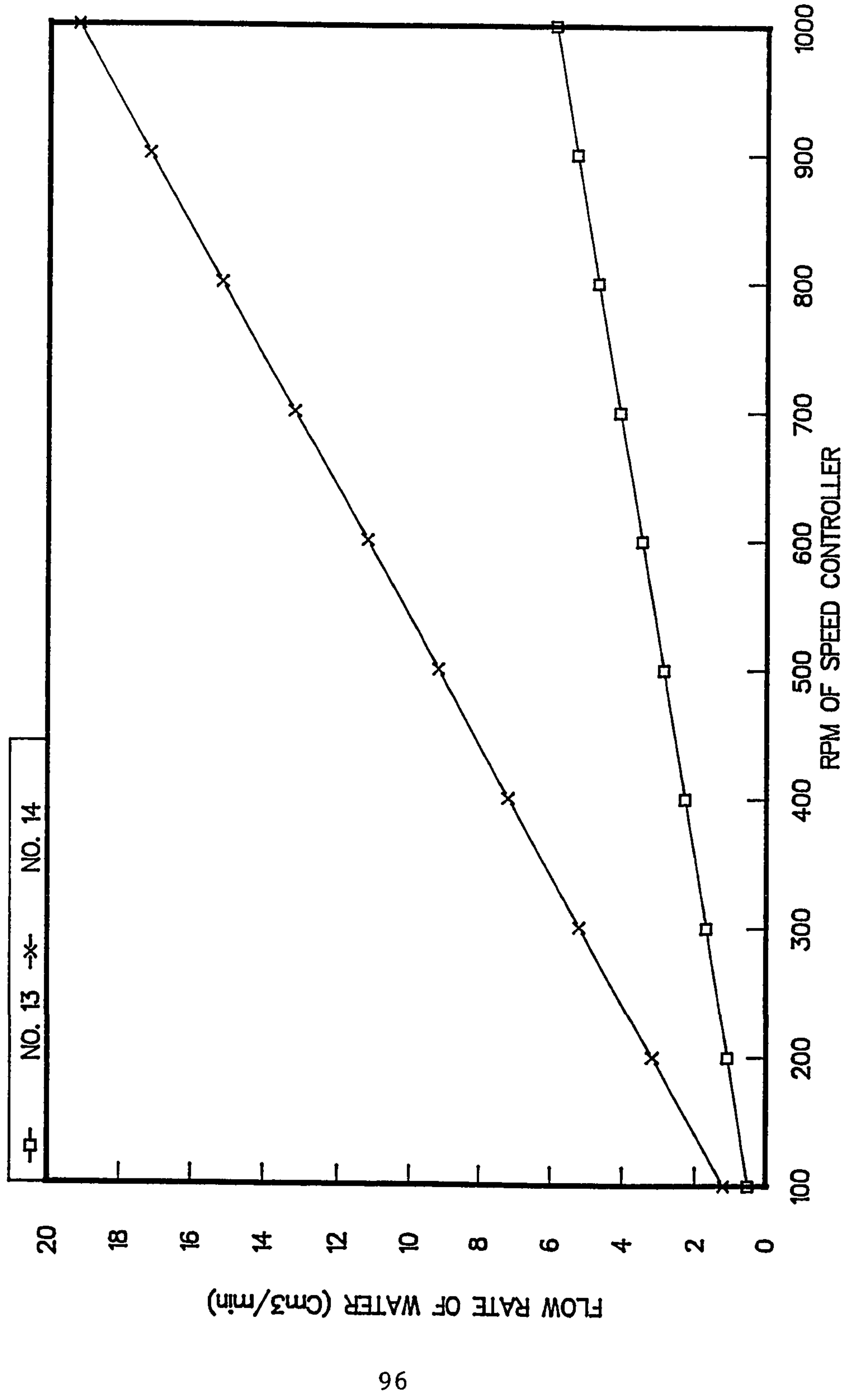
It was found that for the range of rpm $100<rpm<1000$, the flow rate of water was well-represented by a linear equation:

for No 13, $Q = 0.006 \times RPM - 0.1$

for No 14, $Q = 0.02 \times RPM - 0.8$,

where Q = Cm3/min.

FIGURE 18. CALIBRATION OF THE OIL PUMP
USING WATER AT 25 deg C



8.2 Calibration of Atomizing Air and Natural Gas Flows

The compressed air in the laboratory was regulated to 10 psig before running the air through the atomizing air line. Pressure drops were measured by a differential pressure gauge (0 - 10 psi). The voltages produced from the DPT were measured by a multimeter, and the volumetric flow rate of the air was measured by a wet test meter which had a thermometer and a manometer. The DPT was first calibrated by adjusting "span" and "zero" screws to 4 mA at 0 pressure drop and 20 mA at 6 psi of pressure drop. The regulator was opened slowly until the pressure was 0.5 psi, and the voltage, flow rate, pressure, and temperature of the flowing air were recorded. This was for a range of drops to 6 psi. Table 8 shows the air flow rates for the various pressure drops and voltages using the two orifices (Do=0.035" and Do=0.055").

The smaller orifice can be used for a range of flow rates from 0 to 4.35 ft3/hr. The 0.055 inch orifice can be used to measure the range of atomizing air flow rates expected for our system (2.0-6.7 ft3/hr).

Table 8. Air Flow Rate VS Pressure Drop Measured by Wet Test Meter for Do=0.035"

del P (PSID)	SQUARE RT OF del P	CURRENT (mA)	VOLTAGE (V)	Qm(V_RATE OF AIR:FT3/HR) Pa=8PSIG	20PSIG	30PSIG
0.00	0.00	4.00	0.86	0.00	0.00	0.00
0.20	0.45	4.30	0.93	0.28	0.15	0.00
0.40	0.63	4.90	1.05	0.66	0.65	0.54
0.60	0.77	5.40	1.15	0.88	0.89	0.88
1.00	1.00	6.60	1.41	1.24	1.38	1.41
1.50	1.22	7.80	1.65	1.51	1.70	1.93
2.00	1.41	9.20	1.96	1.77	2.00	2.32
2.50	1.58	10.40	2.21	1.97	2.25	2.62
3.00	1.73	11.90	2.53	2.21	2.52	2.97
3.50	1.87	13.30	2.80	2.34	2.80	3.25
4.00	2.00	14.50	3.06	2.55	2.95	3.50
4.50	2.12	15.90	3.34	2.65	3.21	3.74
5.00	2.24	17.10	3.59	2.72	3.35	3.90
5.50	2.35	18.50	3.90	2.82	3.42	4.05
6.00	2.45	20.00	4.20	3.00	3.53	4.35

Air Flow Rate VS Pressure Drop by Wet Test Meter for Do=0.055"

del (PSID)	SQUARE RT OF del P	CURRENT (mA)	VOLTAGE (V)	Qm(V_RATE OF AIR:FT3/HR) Pa=8PSIG	20PSIG	30PSIG
0.00	0.00	4.00	0.86	0.00	0.00	0.00
0.20	0.45	4.20	0.91	0.87	0.52	0.38
0.40	0.63	4.60	0.99	1.45	1.70	1.82
0.60	0.77	5.20	1.12	2.25	2.50	2.56
1.00	1.00	6.30	1.35	3.12	3.60	4.15
1.50	1.22	7.60	1.63	3.78	4.67	4.76
2.00	1.41	9.10	1.93	4.58	5.34	6.08
2.50	1.58	10.40	2.21	5.05	5.65	6.70
3.00	1.73	11.60	2.46	5.30	6.20	7.28
3.50	1.87	13.30	2.80	5.72	6.65	7.80
4.00	2.00	14.50	3.06	6.00	7.12	8.38
4.50	2.12	15.80	3.33	6.20	7.47	8.48
5.00	2.24	17.10	3.59	6.48	7.92	9.05
5.50	2.35	18.50	3.90	6.75	8.15	9.52
6.00	2.45	20.00	4.20	7.00	8.52	9.95

The correlations between standard volumetric flow rate (Qs) and voltage (V) can be found from Table 9 for use in the data acquisition system to compute the atomizing air flow rate. The measured flow rate (Qm) was corrected to the standard flow rate (Qs) by the measuring temperature (Tm) and pressure (Pm). From the ideal gas law,

$$\frac{Pm \times Qm}{Tm} = \frac{Ps \times Qs}{Ts} = \text{a constant}$$

Subscripts "m" and "s" are the measured and standard values, respectively. To determine Qs at Ts and Ps,

$$Qs = (Pm / Ps) \times (Ts / Tm) \times Qm$$

where Ts = 32 F = 491.7 R

Ps = 29.92 in Hg = 760 mm Hg

Pm = Pbr + Pn - Pv

Pbr : Barometric pressure reading

Pn : Manometer reading

Pv : Water vapor pressure at Tm

An approximate linear relationship between voltage, pressure drops, and Q was obtained as follows:

del_P = 1.732452 x V - 1.51884

Qs = 2.487 x (del_P)^0.64

Thus, Qs = 2.487 x (1.732452 x V - 1.51884)^0.64

Table 9. Calibration for Atomizing Air Line Using Do=0.055"

dP(PSI)	VOLTAGE	Qm(FT3/HR)	T(F)	Pbr(PSIG)	Pbr(inHg)	Pv(mmHg)
0.0000	0.8767	0.0000	71.7000	0.0000	0.0000	0.0000
0.5000	1.1100	1.7500	71.7000	0.2000	30.1200	19.9000
1.0000	1.4400	2.8000	71.5000	0.5000	30.4200	19.8000
1.5000	1.7100	3.5100	71.5000	1.0000	30.9200	19.8000
2.0000	2.0200	4.1000	71.2000	2.0000	31.9200	19.5200
2.5000	2.3000	4.5600	71.0000	2.8000	32.7200	19.4100
3.0000	2.5800	5.0200	70.8000	3.2000	33.1200	19.3000
3.5000	2.8900	5.4600	70.5000	3.9000	33.8200	19.1000
4.0000	3.2000	5.8000	70.3000	4.3000	34.2200	18.9500
4.5000	3.4800	6.1400	70.1000	5.0000	34.9200	18.8500
5.0000	3.7500	6.4700	69.8000	5.5000	35.4200	18.6500
5.5000	4.0400	6.7600	69.5000	6.2000	36.1200	18.5000
6.0000	4.3400	6.9300	69.2000	7.6000	37.5200	18.2400

Pn(inHg)	Pm(inHg)	Tm(R)	Qs	SQRT_dP	Qcal	Qcal-Qs
0.0000	0.0000	531.4000	0.0000	0.0000	0.0003	0.0003
0.0111	29.3477	531.4000	1.5883	0.7071	1.3928	-0.1955
0.0133	29.6538	531.2000	2.5687	1.0000	2.4485	-0.1203
0.0133	30.1538	531.2000	3.2744	1.2247	3.1458	-0.1286
0.0133	31.1648	530.9000	3.9553	1.4142	3.8516	-0.1037
0.0133	31.9692	530.7000	4.5143	1.5811	4.4313	-0.0830
0.0141	32.3742	530.5000	5.0345	1.7321	4.9710	-0.0635
0.0141	33.0821	530.2000	5.5987	1.8708	5.5325	-0.0662
0.0141	33.4880	530.0000	6.0225	2.0000	6.0635	0.0410
0.0148	34.1927	529.8000	6.5122	2.1213	6.5216	0.0094
0.0148	34.7006	529.5000	6.9681	2.2361	6.9468	-0.0213
0.0148	35.4065	529.2000	7.4327	2.3452	7.3877	-0.0450
0.0155	36.8175	528.9000	7.9278	2.4495	7.8288	-0.0990

Qcal=2.4870x(dP^0.64)   dP=1.73245xV-1.51884

FIGURE 19. PRODUCED VOLTAGE FOR AIR LINE

VOLTAGE VERSUS del_P

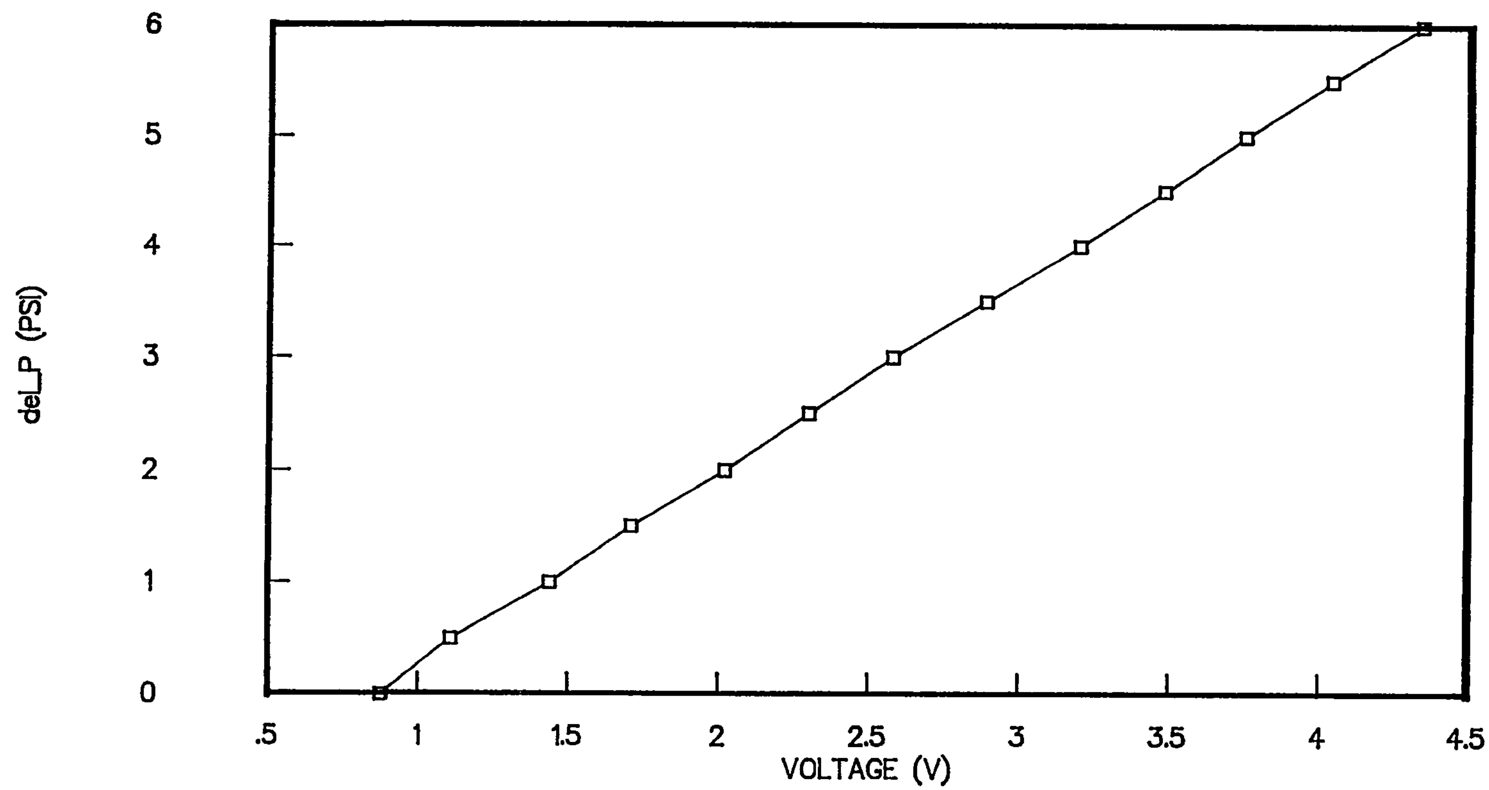
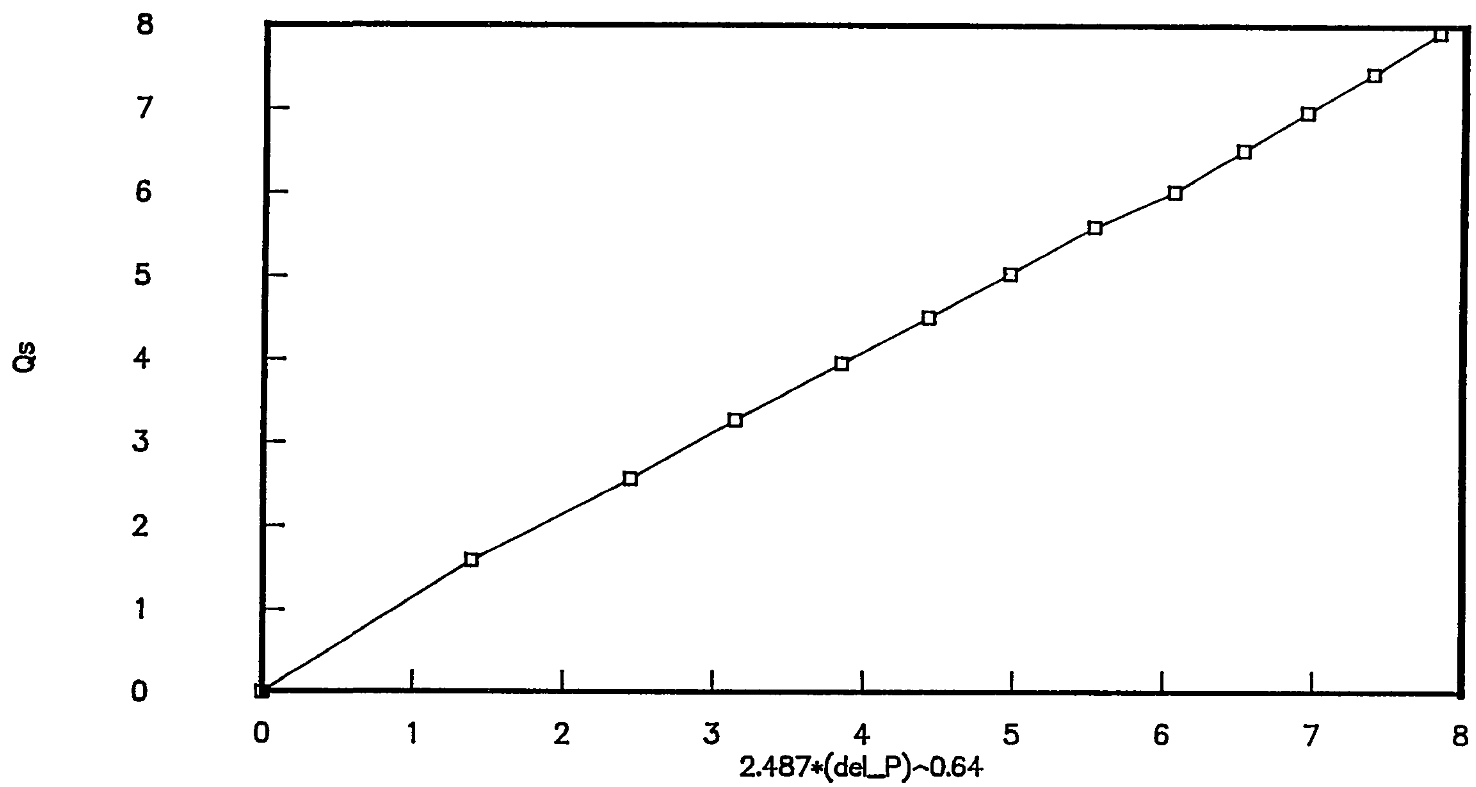


FIGURE 20. CALIBRATION FOR AIR LINE

AIR FLOW RATE VERSUS del_P USING Do=0.055"



The flow measurement for the natural gas line was tested using regulated air. A differential pressure gauge was used to measure the pressure drop, from 0 to 25 in H_2O, through the 0.128 inch orifice diameter. The pressure drop was nearly linear in the voltage produced from the DPT.

$$del\_P = 0.2615 \times V - 0.2298$$

The pressure drop was not perfectly linear with respect to Qs. The best-fit formula:

$$Qs = 10^{(0.4132 \times \log(del\_P) + 1.05)}$$

Thus, $Qs = 10^{(0.4132 \times \log(0.2615 \times V - 0.2298) + 1.05)}$ is shown on Figure 21. The units of the Q and V are ft3/hr and volts respectively.

Table 10. Calibration for Natural Gas Line Using Do=0.128"

dP(inH2O	VOLTAGE	Qm(FT3/HR)	T(F)	Pbr(PSIG)	Pbr(inHg)	Pv(mmHg)
0.0000	0.8788	0.0000	62.5000	0.0000	0.0000	0.0000
2.0000	1.1000	3.8800	63.0000	0.0000	29.9200	14.7700
4.0000	1.3400	5.4100	63.1000	0.0000	29.9200	14.8000
6.0000	1.5850	6.5500	63.1000	0.0000	29.9200	14.8000
8.0000	1.9000	7.7800	63.2000	0.0000	29.9200	14.8300
10.0000	2.1800	8.6800	63.1000	0.0000	29.9200	14.8000
12.0000	2.4800	9.2500	63.1000	0.4000	30.3200	14.8000
14.0000	2.7800	9.6400	63.0000	1.0000	30.9200	14.7400
16.0000	3.0700	9.8300	62.6000	1.5000	31.4200	14.5300
18.0000	3.3700	9.9100	62.5000	1.9000	31.8200	14.4800
20.0000	3.6500	10.0700	62.3000	2.2000	32.1200	14.4000
22.0000	3.9400	10.2000	62.0000	2.4000	32.3200	14.2000
24.0000	4.2000	10.4000	61.8000	2.6000	32.5200	14.1000
25.0000	4.3300	10.4800	61.8000	2.8000	32.7200	14.1000

Pn(inHg)	Pm(inHg)	Tm(R)	Qs	LOG(Qs)	LOG(dP)	Qcal	Qs-Qcal
0.0000	0.0000	522.20	0.0000	0.0000	-5.207	0.0637	-0.0637
0.0148	29.3533	522.70	3.5808	0.5540	-1.237	3.2833	0.2975
0.0155	29.3529	522.80	4.9917	0.6983	-0.918	4.5071	0.4847
0.0200	29.3573	522.80	6.0445	0.7814	-0.733	5.4160	0.6285
0.0296	29.3658	522.90	7.1803	0.8561	-0.573	6.3496	0.8307
0.0392	29.3766	522.80	8.0154	0.9039	-0.468	7.0489	0.9665
0.0503	29.7877	522.80	8.6613	0.9376	-0.378	7.7086	0.9527
0.0592	30.3989	522.70	9.2134	0.9644	-0.303	8.3010	0.9124
0.0673	30.9153	522.30	9.5619	0.9805	-0.241	8.8251	0.7369
0.0792	31.3291	522.20	9.7707	0.9899	-0.186	9.3271	0.4435
0.0888	31.6419	522.00	10.0314	1.0014	-0.139	9.7655	0.2659
0.0947	31.8557	521.70	10.2354	1.0101	-0.096	10.1937	0.0417
0.1021	32.0670	521.50	10.5094	1.0216	-0.061	10.5584	-0.0490
0.1066	32.2715	521.50	10.6577	1.0277	-0.044	10.7346	-0.0769

Qcal=10^(0.4132xLOG(dP)+1.05) dP=0.2615xV-0.2298

FIGURE 21. PRODUCED VOLTAGE FOR NATURAL GAS LINE

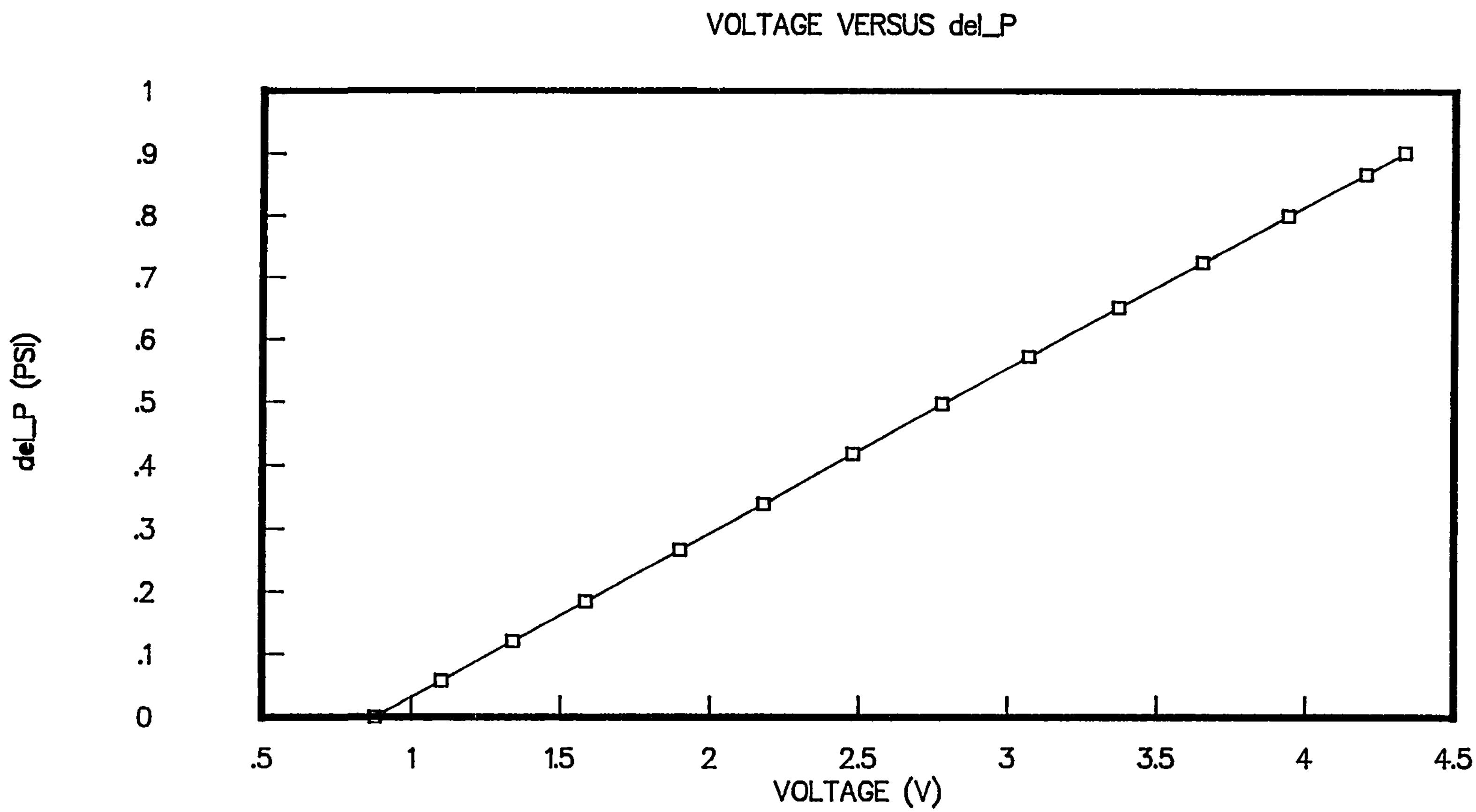
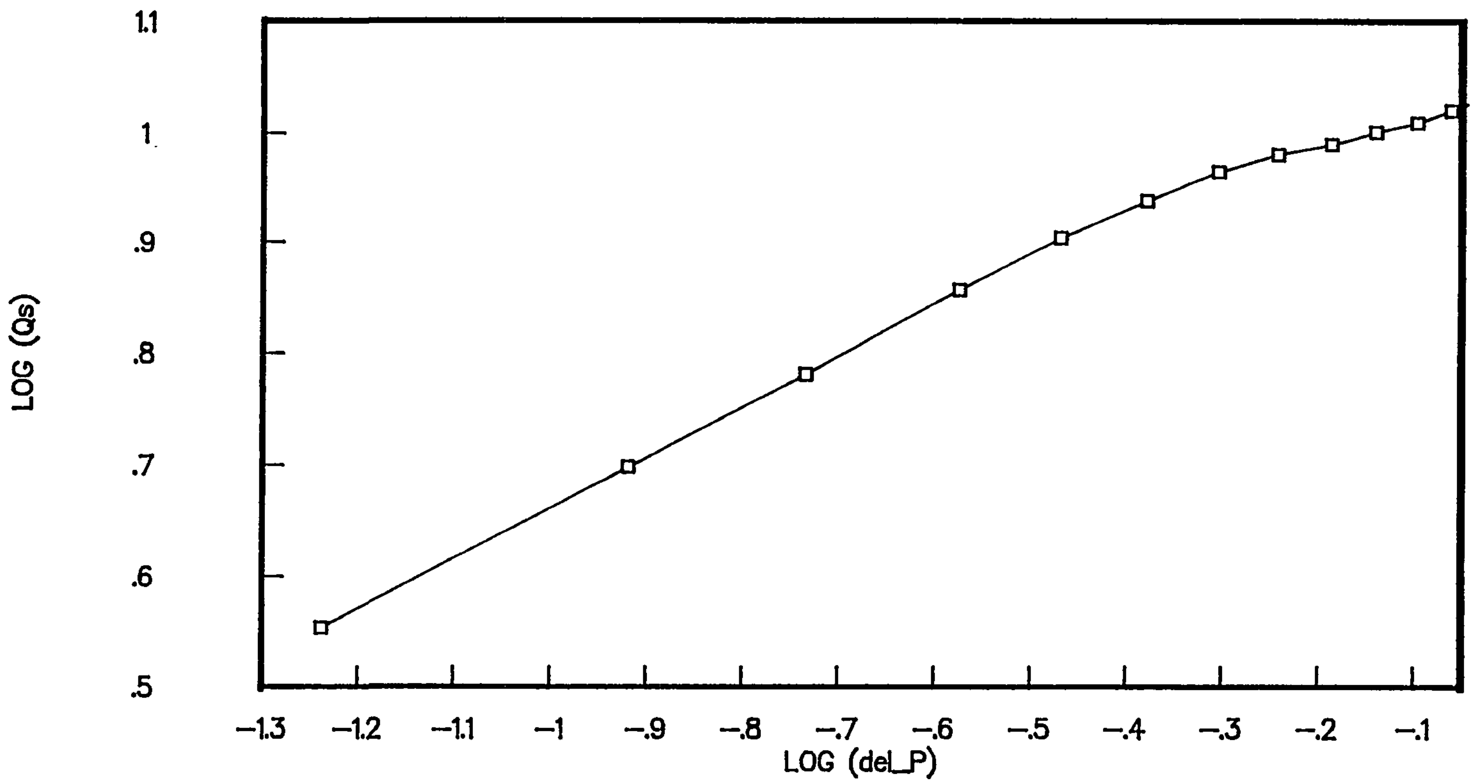


FIGURE 22. CALIBRATION FOR NATURAL GAS LINE

AIR FLOW RATE vs del_P USING Do = 0.128"



8.3 Data Acquisition System

All formulas discussed previously were entered into the Measure data acquisition module and the 1-2-3 spreadsheet to convert actual flow rates and temperatures using the produced voltages from the instruments (DPTs, thermocouples). In order to do that, the hardware must be connected properly. Two Lab-PC boards (Lab-PC I for temperature measurement, Lab-PC II for flow measurement) and one RS-232 board for the emission analyzer were installed in three of the 8-bit expansion slots in the computer with proper configuration settings. The Lab-PC boards were configured by the Data Acquisition Module hardware default values in the Data Acquisition Module Reference. Board number 0 was selected for the Lab-PC I and 2 for the Lab-PC II.

	Board No	I/O Address	DMA	Interrupt Level
Lab-PC I	0	0260H	3	5
Lab-PC II	2	02A0H	3	7

Following the Lab-PC user's manual, the setting for the Lab-PC II was only performed since the configuration setting at the factory was the same as the one for Lab-PC I. All accessories described in section 6.3 were connected to the

Lab-PC boards. The serial port of the RS-232 board was labeled at "com1", and then the board was connected to the one in the analyzer through the D-type modem cable.

The Measure software was added to the 1-2-3 spreadsheet to be used with the Lab-Pc boards. To set up the data acquisition experiment in Measure, the board numbers and the input channels to be used were identified as follows:

Table 11. Identification of the Board No. and the Channel No. in the Lab-PC Boards

TEMPERATURE MEASUREMENT (LAB-PCI)			FLOW MEASUREMENT (LAB-PCII)		
TC_MODULE	CHANNEL_No	BOARD_No	DPT	CHANNEL_No	BOARD_No
TYPE J	0	0	GAS	0	1
TYPE R	1	0	ATM_AIR	1	1
TYPE K	2	0			
TYPE K	3	0			
TYPE K	4	0			
TYPE K	5	0			

Procedures for setting up the module and acquiring the data are followed by the Data Acquisition Module Reference.

ENERCOMP software package was used with the RS-232 board. The ENERCOMP consists of two programs; the first program (C2000) converts the computer into the monitor and data storage device, and the second program (EES_123) converts the combustion analysis data stored into the proper format for use with the 1-2-3 spreadsheet. This makes the data analyzed be combined with other data (flow rates and temperatures) and displayed in a form. The software was installed by following the ENERCOMP Instruction Manual [23]. The instruction manual for operation of the data acquisition system is included in the operational manual in Appendix E.

Tables 12 and 13 show data for a flow and temperature measurement experiment and for an analysis using the emission analyzer. The experiment was performed at room temperature with no any air flow through the two lines (gas and atomizing air line). Two TC modules, type J at channel 0 and type K at channel 2 in the Lab-PC I, were connected to the thermocouple wires. Two DPTs were connected to channel 0 and 1 in the Lab-PC II. One hundred samples for each measurement were collected at a rate of 10 samples/second. The average of them was converted into the actual data by the formula. The temperature from channel 0 (type J) was the same one measured by the thermometer. The temperature from channel 2 (type K) was lower than the actual temperature because of the gain factor. Temperatures from channel 1, 3, 4, and 5 were maximum temperatures of the type R (1750°C) and K (1350°C) since the TC modules (without thermocouple wires) produced maximum voltages by the power supply. Since the formula from the flow calibration was not linear, the data do not give zero flow rate when no gas is flowing.

Table 12. Test Results of Flow and Temperature Measurement Using Data Acquisition

Lab-PC I					
Chanl 0	Chanl 1	Chanl 2	Chanl 3	Chanl 4	Chanl 5
TYPE J	TYPE R	TYPE K	TYPE K	TYPE K	TYPE K
1.407	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111

1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.067	54.111	54.111	54.111
1.407	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111
1.383	18.499	1.067	54.111	54.111	54.111
1.383	18.499	1.039	54.111	54.111	54.111

	1.383	18.499	1.067	54.111	54.111	54.111
	1.407	18.499	1.067	54.111	54.111	54.111
	1.407	18.499	1.039	54.111	54.111	54.111
	1.407	18.499	1.067	54.111	54.111	54.111
	1.383	18.499	1.067	54.111	54.111	54.111
	1.407	18.499	1.039	54.111	54.111	54.111
	1.383	18.499	1.067	54.111	54.111	54.111
	1.383	18.499	1.067	54.111	54.111	54.111
	1.383	18.499	1.039	54.111	54.111	54.111
	1.407	18.499	1.067	54.111	54.111	54.111
	1.383	18.499	1.039	54.111	54.111	54.111
	1.383	18.499	1.039	54.111	54.111	54.111
mV	1.392	18.499	1.056	54.111	54.111	54.111
V	0.001	0.018	0.001	0.054	0.054	0.054
C	27.216	1749.537	25.812	1349.508	1349.508	1349.508
F	80.989	3181.166	78.461	2461.115	2461.115	2461.115

Lab-PC II Chanl 0	 Chanl 1
GAS_DP	ATM_DP
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.877	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.877	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877

0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.877	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.877	0.877
0.879	0.877
0.879	0.877
0.877	0.877
0.879	0.877
0.877	0.877
0.877	0.877
0.879	0.877
0.879	0.877
0.877	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.879
0.877	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877
0.879	0.877

	0.879	0.877
	0.877	0.877
	0.879	0.879
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.877	0.877
	0.877	0.877
	0.877	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.877	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
	0.879	0.877
VOLTAGE (V)	0.879	0.877
FLOW(FT3/HR)	0.032	0.003

Table 13. Data from Experiment using the Emission Analyzer

```
**DATA ANALYSIS BY THE EMISSION ANALYZER**
ENERAC  TIME:   13:46:23   DATE:  09/18/90*
* STACK TEMPERATURE:              34  ?C    *TEMP     (DEG C)
* AMBIENT TEMPERATURE:            28  ?C    ****************
* CARBON MONOXIDE:                 0 PPM    *OIL  :     27.216
* OXYGEN:                       19.4   %    *FLAME:   1749.537
* COMBUSTIBLE GASES:            0.00   %    *TEMP1:     25.812
* CARBON DIOXIDE:               00.9   %    *TEMP2:   1349.508
* EXCESS AIR:                   OVER   %    *TEMP3:   1349.508
* COMBUSTION EFFICIENCY:        87.8   %    *TEMP4:   1349.508
* OXIDES of NITROGEN:              0 PPM    *
* SULFUR DIOXIDE:                  0 PPM    *
                                            *FLOW(FT3/HR)
                                            *************
                                            *ATM AIR:    0.032
                                            *N_GAS  :    0.003
                                            *
                                            *
                                            *OIL_FLOW(CM3/MIN)
                                            ******************
                                            *RPM    : 200.000
                                            *RATE   :   3.200
```

8.4 Test of the Flame Safeguard Control System

This system was tested partially first, using the pressure, temperature switch, or the push button as an input device and the solenoid valve as an output device with the PLC.

For the natural gas line, the acceptable low and high pressure limits (4 and 15 in H2O) were set in the gas pressure switch. Four electrical wires from the pressure switch were connected to the power supply and the PLC. Two were for the hot line and common line of the power, and two for the input terminal block and the common line of the PLC. Two wires from the pilot gas shutoff valve (normally-closed) were connected to the PLC and the power, one for the output terminal block of the PLC and the other for the common of the power. The hot line of the power was connect to the PLC. Simple instructions were programmed into the PLC; for example, the pilot gas shutoff valve was to be energized when the pressure was within the acceptable limits. Regulated air was run through the gas line, and the RUN mode on the PLC was pushed. When the pressure was 6 in H2O, the pilot gas shutoff valve was automatically energized and opened. The valve auto-matically closed (de-energized) when the pressure was 17 in H2O.

For the oil line, temperature limits were set at

20 and 30°C in the low and high temperature switches, respectively. The electrical wiring for the single switch (temperature switch) is different from the dual switch (pressure switch). For the single switch, one lead is connected to the hot of the power and the other is connected to the input terminal block of the PLC. The common line of the power is connected to the common of the PLC. A recycling shutoff valve (normally-open) and a main oil shutoff valve (normally-closed) were wired to the PLC as output devices. A simple program instructs that the two shutoff valves are to be energized when the measured temperature is within the two set points. Water at 18°C was pumped from the container in the tank, and the RUN mode on the PLC was pushed. The water was automatically recycled until the temperature of the water was 20°C. When the temperature was 20°C, the recycling valve closed and the main oil valve opened, thus completing a successful test at high temperature. In order to test the system at low temperature, some ice was poured into the container. When the line temperature dropped below 19°C, the recycling and the main oil solenoid valves were de-energized, which returned the unpowered condition.

In order to test the air fan, a timer function of the PLC was used. A Purge Start push button was wired to the input terminal of the PLC like the single switch, and the air fan was wired to the output terminal like the shutoff valve. The program selected allowed for the air fan to be on 90 seconds after pushing the start button. When tested, the air fan remained on for exactly 90 seconds. After these verifications that parts of the automatic system work properly, the electrical wiring diagrams (Figure 22, Figure 23) was established.

FIGURE 23. ELEMENTARY WIRING DIAGRAM

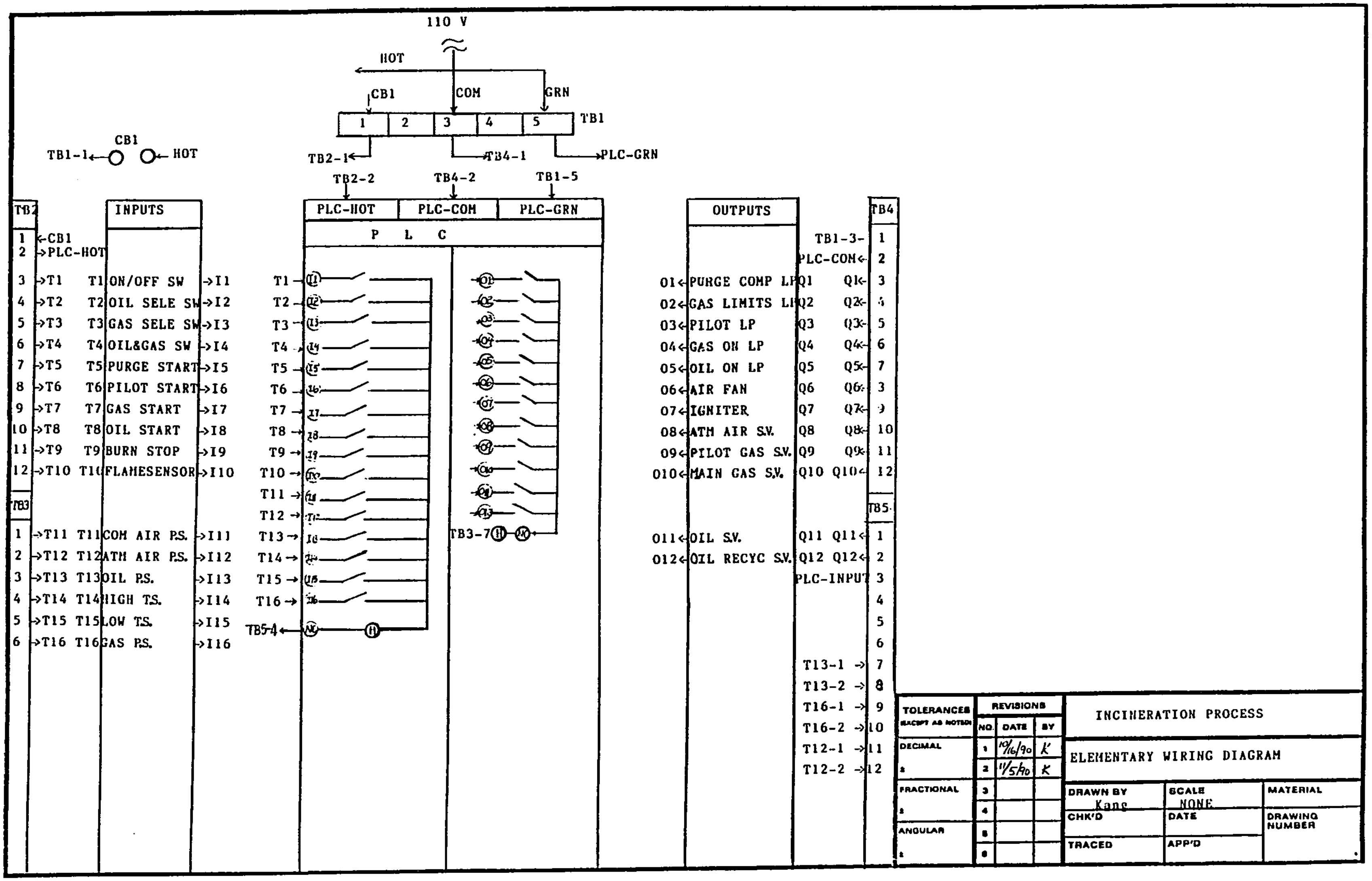
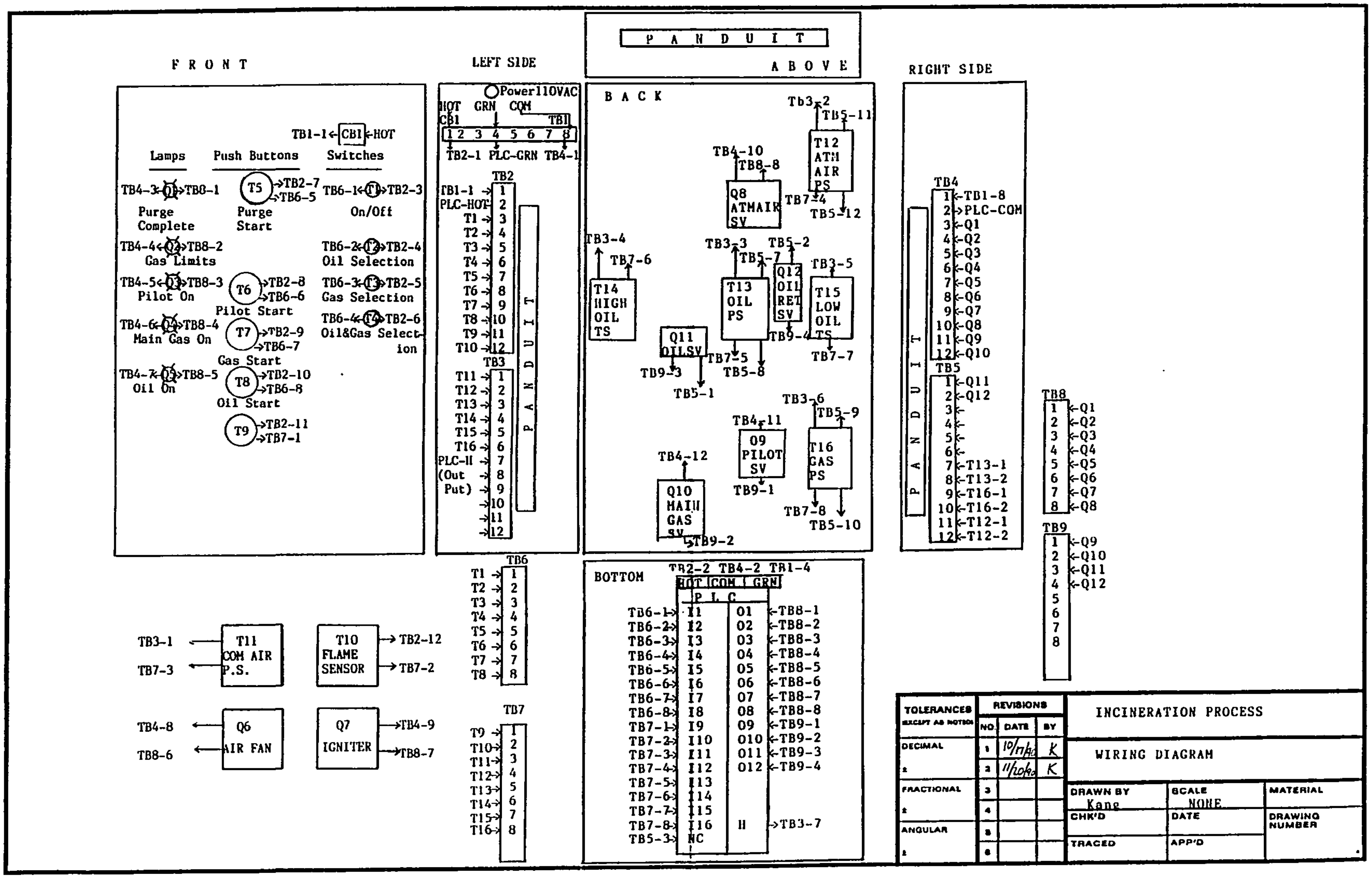


FIGURE 24. WIRING DIAGRAM



CHAPTER 9. DISCUSSION AND CONCLUSIONS

The data acquisition system was designed, constructed, and tested for the flow and temperature measurement and gas monitoring. The system was operated semi-automatically with the PLC. The process was manually monitored step by step using the push button; however, all flows were controlled automatically by the limit switches and the interlocks, following the program in the PLC. Tests showed that the safety system and the data acquisition system were operable. Temperature and flow calibration were correct. Thus, one stated objective of this work, the design and construction of required safety and measurement systems for the incinerator, has been successfully achieved.

The second objective, that of completing a preliminary design, has been met. Enough supporting calculation have been presented to enable future workers to easily understand and modify the proposed design.

The next step will be the installation of the burner and burner block. The burner unit will be flanged to the front of the existing combustion chamber. Tubing lines (oil, atomizing air, and natural gas) from the instrumentation cabinet will be connected to the burner block. Last, the duct fan, encased in the windbox, will be installed at the rear of the burner block. Supports and stack have already been fitted to the chamber, so the installation can proceed immediately in the selected courtyard.

The tests planned for initial operation are as follows:

<1> run the system for simulation

<2> combust methane gas

<3> check temperatures, flow rates, and stack gas concentrations against predictions to verify unit operation

<4> repeat test with kerosene.

After testing has been completed, the incinerator will be available for use as a laboratory in chemical engineering courses. The following experiments are planned. It is expected that these will be tested and modified, then written up into a formal experimental procedure, by undergraduates in these classes. Planned experiments in ChE 177 are

<1> adjust fuel/air ratio to find the influence on the gas stack concentrations

<2> vary atomizing air pressure to effect on combustion efficiency

<3> use a tracer compound (eg, SF6) to check the performance of the incinerator.

In summary, a feasible design for a laboratory scale incinerator has been developed. The design features computerized data acquisition and automated safety control, both of which systems have been constructed and tested. The laboratory function of the incinerator has been clearly described and recommendations for its use have been made.

REFERENCES

1. Theodore and Reynolds, Introduction to Hazardous Waste Incineration, 1987
2. U.S. EPA, "Engineering Handbook on Hazardous Waste Incineration", SW-889, NTIS PB 81-248163, Sep 1981
3. W.R. Niessen, Combustion and Incineration Process, Marcel and Dekker, 1978
4. C.A. Brunner, Incineration Systems and Selection and Design, Van Norstrand Reinhold Co., 1984
5. U.S. EPA, Hazardous Waste Data Management System, Listing of Incineration Facilities, Aug 11,1987
6. John H. Seinfeld and Richard C. Flagan, Fundamentals of Air Pollution Engineering, Prentice-Hall, 1988
7. Pompei, F., and Heywood, J.B., "The Role of Mixing in Burner-Generated CO and NO" Comb.Flame,19,407-418,1972
8. The American Society of Mechanical Engineers, Hazardous Waste incineration, Jan 1988
9. B. Dellinger, W.A. Rubey, D.L. Hall, and J.L. Graham, "Incinerability of Hazardous Wastes", Hazardous Waste and Hazardous Materials, Vol 3, No 2, 1986
10. U.S. EPA, " Hazardous Waste Management System: Identification of Listing of Hazardous Waste", Federal Register 45 (98,Part III), May 19, 1980

11.U.S. EPA, "Hazardous Waste Proposed Guidelines and Regulations and Proposal on Identification and Listing", Federal Register 43 (243, Part IV), Dec 18,1987

12.W.L. Nelson, Petrochemical Refinery Engineering, McGraw-Hill, 1958

13.Perry, Chemical Engineering Handbook, 6th ED, Chapter 22

14.J.R.Pfaffin and Edward N.Ziegler, Encyclopedia of the Environmental Science and Engineering, Vol 3, 1983

15.Incropera De Witt, Fundamentals of Heat and Mass Transfer, 2nd Ed, Wiley, 1985

16.Energy Efficiency System, Inc., Instruction manual of Combustion Analyzer Model 2000, Oct 1989

17.La Fonda, Kramlich, Seeker, and Samuelsen, "Evaluation of Continuous Performance Monitoring Technics for Hazardous Waste Incinerators", Journal of the Air Pollution Control Association, Vol 35, No 6, June 1985

18.Stanley M. Walas, Chemical Process Equipmen, Butterworths, Page 95, 1988

19.National Instruments, Lab-PC User's Manual,1989

20.National Instruments, Data Acquisition Module Reference, 1989

21.U.S. National Bureau of Standards, "Thermocouple Reference Tables Based on the IPTS-68" Monograph 25,

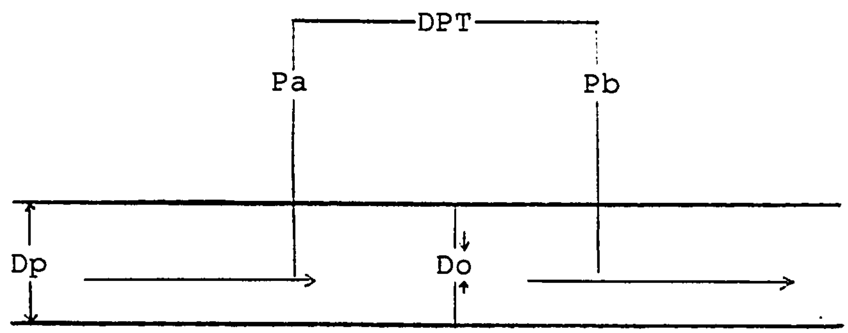
22.National Fire Protection Association, National Fire Code, Vol 7, 1980

23. Energy Efficiency System, Inc., ENERCOMP Instructional Manual, June 1989

24. G.E. Fanuc Automation, Series 90-30 Programmable Controller User's Manual, Feb 1990

25. C. David Cooper and F.C.Alley, Air Pollution Control A Design Approach, Waveland Press, Inc., 1986

Appendix A. Calculation To Estimate Orifice Diameter (Do)



The pressure drop (P = Pa-Pb) is calculated by an equa-ion for the flow of compressible fluids through orifice [17].

$$del\_P = \frac{M}{Co\ Y\ So} \times \frac{M}{Co\ Y\ So} \times \frac{(1 - b^4)}{2\ gc\ d} \quad \text{(Eq A)}$$

M(lb/sec): Mass flow rate of atomizing air

Co : Orifice coefficient

Y : Expansion factor

gc : Newton's-law conversion factor (32.174 lb Ft/lbf sec2)

d : Density of air at 80 F (0.0752 lb/ft3)

Dp(inch) : Inside diameter of pipe (0.622 in)

Do(inch) : Orifice diameter

b (Do/Dp): Ratio of Do and Dp

So(ft2) : Surface area of orifice

del_P(psi): Pressure drop (Pa - Pb)

From the Eq A,

$$So = \frac{M \quad SQRT((1 - b)^4)}{Co \; Y \quad SQRT(2 \; gc \; d \; del\_P)} \qquad (Eq\ B)$$

$$So = \frac{Dp^2 \quad So}{Dp^2} = \frac{Dp^2 \quad (pi \; Do)^2}{Dp^2} = \frac{pi \; (Dpb)^2}{4} \qquad (Eq\ C)$$

From the Eq B and Eq C,

$$Do^2 = \frac{4 \; M \quad SQRT(1 - b^4)}{Co \; Y \; pi \; SQRT(2 \; gc \; d \; del\_P)}$$

Recommended values for Co and Y are 0.75 and 1.0, respectively, according to industrial source.

Appendix B. Correction Factor for the TC Module Gain and Polynomials

This section describes how thermocouple signals are linearized when using the thermocouple (TC) signal conditioning module (input module). TCs generate low voltage signals that represent temperature in a non-linear fashion. Before the actual temperature of the TC can be determined, the signal from the thermocouple must first be amplified and corrections made for its non-linear nature. The thermocouple input module amplifies the voltage appearing at the TC input terminals of the modules, usually in the mV range. The output of this amplifier is a voltage from 0V to 5V depending upon the temperature of the TC junction (for example, -100°C - +1350°C for K-type TC). The range is calibrated by Analog Devices, the manufacturer of the modules used in this system. The way that the output varies from 0V to 5V does not, however, correspond to the temperature of the TC junction in a linear fashion. This is a physical characteristic of TC's. This non-linear nature can be corrected for by application of a polynomial correction factor prepared by the National Institute of Standards and Technology [21], found in references such as the Omega Handbook. From the handbook one can look up values for TC modules at the temperatures specified by our module.

This leads to the following table of values:

TABLE 14. TEMPERATURES VS VOLTAGES FROM TC

TC TYPE	TEMP	VOLTAGES FROM TC	VOLTAGE OF TC MODULE
K	-100C	-3.553 mV	0V
	+1350C	54.125 mV	5V
J	-100C	-4.632 mV	0V
	+760C	42.922 mV	5V
R	0C	0.0 mV	0V
	+1750C	20.878 mV	5V

To compute the gain of the TC module from this data is a simple task of applying a linear equation, as the TC module can be thought of as a linear amplifier of TC voltage. For example, for the K-type of TC module,

$$V\_TC = -3.553 \text{ mV} + \frac{(54.125 - (-3.553))\text{mV}}{(5 - 0)\text{V}} \times V(\text{K-type module})$$

This equation will yield the actual voltage of the TC junction, which is the data that is sought for the NBS polynomial fit equation. At this point we can apply the NBS coefficients. Table 15 lists the NBS polynomial coefficients [21] for several commonly used thermocouples.

Upon examination of a table of these numbers we see that they are valid for only a certain range of temperature ($0^{\circ}C$ — $1370^{\circ}C$ for K-type TC). This limits this technique to values above $0^{\circ}C$. The polynomial is programmed in a nested format;

$$T = a0 + Vx(a1 + Vx(a2 + Vx(a3 + Vxa4)))$$

such that no powers are computed, and execution proceeds much faster. The results of these equations will be the actual junction temperature of the thermocouple, the quantity that we sought to measure in the first place.

Table 15. NBS Polynomial Coefficients

Type	E	J	K	R	S	T
Temp Range	-100° C to 1000° C ± 0.5° C[1]	0° C to 760° C ± 0.1° C[1]	0° C to 1370° C ± 0.7° C[1]	0° C to 1000° C ± 0.5° C[1]	0° C to 1750° C ± 1° C[1]	-160° C to 400° C ± 0.5° C[1]
a_0	0.104967248	-0.048868252	0.226584602	0.263632917	0.927763167	0.100860910
a_1	17189.45282	19873.14503	24152.10900	179075.491	169526.5150	25727.94369
a_2	-282639.0850	-218614.5353	67233.4248	-48840341.37	-31568363.94	-767345.8295
a_3	2695339.5	11569199.78	2210340.682	1.90002E + 10	8990730663	78025595.81
a_4	-48703084.6	-264917531.4	-860963914.9	-4.82704E + 12	-1.63565E + 12	-9247486589
a_5	1.10866E + 10	2018441314	4.83506E + 10	7.62091E + 14	1.88027E + 14	6.97688E + 11
a_6	-1.76807E + 11		-1.18452E + 12	-7.20026E + 16	-1.37241E + 16	-2.66192E + 13
a_7	1.71842E + 12		1.38690E + 13	3.71496E + 18	6.17501E + 17	3.94078E + 14
a_8	-9.19278E + 12		-6.33708E + 13	-8.03104E + 19	-1.56105E + 19	
a_9	7.06132E + 13				1.69535E + 20	

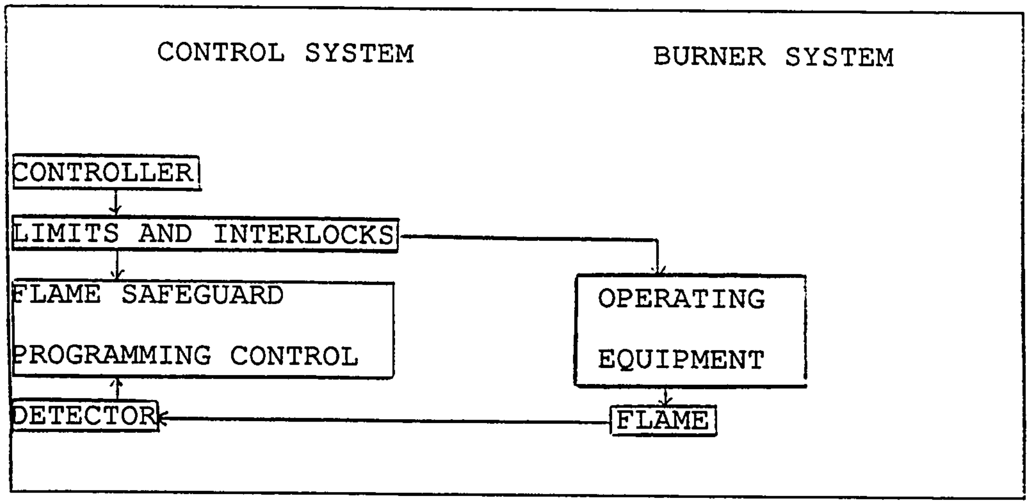
[1] The accuracies shown apply only to the polynomial and do not take into consideration errors introduced by the SC-2070, the SC-2071, the AMUX-64T, the MIO-16, or the thermocouple itself.

Source: NBS Monograph 125, Thermocouple Reference Tables (National Bureau of Standards, Washington D.C. 1979)

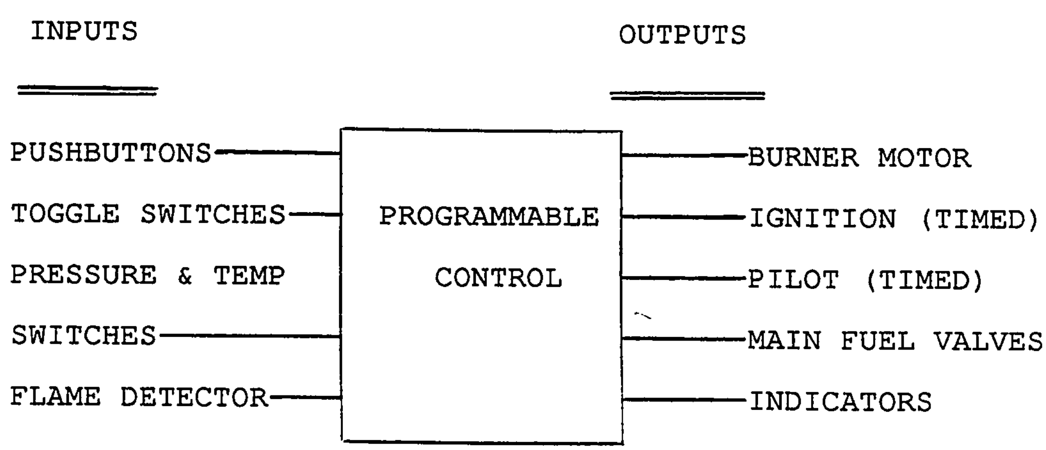
Note: For the formulas in Table 15, the voltages are in volts.

Appendix C. Theory of Programmable Control Operation

The flame safeguard system is a set of control equipment used to provide safe control of burner operation. This includes flame sensing device used to detect the flame, operating and safety devices used to start and stop the burner, valves to control fuel flow, sequencing relays, and auxiliary controls used in conjunction with the burner safety control systems. Primary functions performed by the flame safeguard system are to provide a safe means of starting and stopping the burner, either manually or automatically, to start the burner in the proper sequence, and to supervise the burner flame during operation. The programmable control, with its associated flame detector, is the heart of the control system. A generalized flame safeguard control system is shown in the following figure.



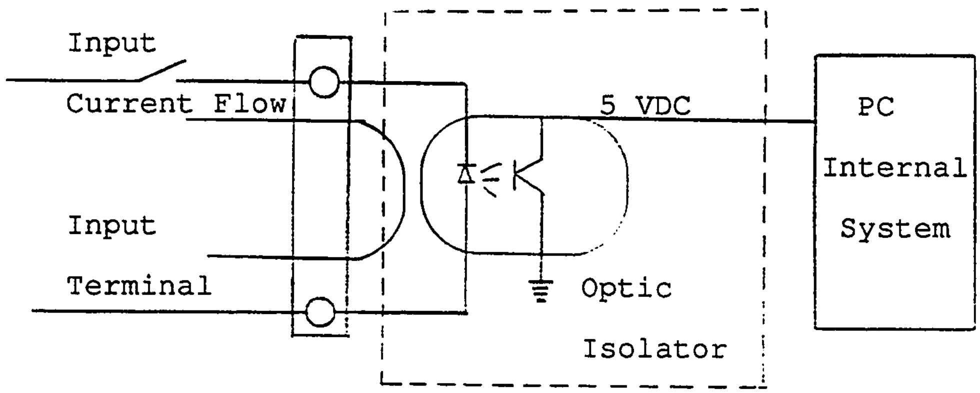
From the figure, it is apparent that the programmable control starts the burner system on a signal from the controller, and permits operation to continue under control of two feedback loops. The flame detector monitors flame conditions and signals the burner to stop if the flame is lost, or if a failure occurs in the detection system. The limits and interlocks, including fuel pressure switches and temperature switches, monitor conditions other than the presence of flame, shutting down the system if conditions exceed limit or interlock settings. In addition to the primary functions performed by the flame safeguard system, the programmable control provides timed sequencing of the burner functions as well as control of additional functions, such as prepurge, postpurge, timed trial for ignition, and firing rate selection. In summary, the programmable control translates inputs from the flame detector, limits, and interlocks into sequenced control of the burner motor, ignition, pilot, and mainfuel valves. The ignition, pilot, and main fuel valves are timed by the programmable control. The following figure describes the functions of programmable control [24].



PROGRAMMABLE CONTROL INPUTS/OUTPUTS

That is, the programmable control will not energize the ignition transformer and pilot valve until the prepurge period is over, and it will not energize main fuel valves (solenoid valves) until pilot has been proven.

We chose a programmable logic controller (PLC) unit manufactured by G.E.Fanuc. The unit consists of 16 point input, 12 points output, and hand-held programmer.



INPUT CIRCUIT IN PLC

The input device either allows current flow to the PLC, or interrupts current flow to the PLC in order to advise the controller of an existing condition. Within the PLC, input and output voltages are isolated from the PLC by optical isolators. The illustration above shows an input circuit. The optic isolator consists of light emitting diode (LED) and photosensitive transistor. When the input is closed, current flows through the LED, causing it to light. When this occurs, the photosensitive transistor turns on, causing a +5 Vdc signal to be routed to the internal PLC system. This signal represents an ON condition for the input device.

Every set of input field terminals has its own input circuit, providing electrical isolation between the input circuits and the PLC. The central processor unit (CPU) of the PLC uses the field terminal number as a reference number for each position in the input status table. The CPU coordinates, sequences, utilizes, and controls all other parts of the PLC. The current status of all inputs is stored in a table in the PLC in the form of an ON or an OFF. All inputs are represented by either a 1 or a 0 in the input table. Once the CPU has this information available in the input table, it can make use of the instructions we have programmed into memory. The CPU makes use of the input table and the program to decide what it should do to outputs. If the program instructs the CPU to energize an output for a given input condition, the CPU will perform this action through the use of the output table and output circuit, allowing the output device to be energized. Outputs are controlled with output circuits, which are almost identical to input circuits.

Appendix D. Permit Procedures and Requirements

Information to get a permit for operating the incinerator had been obtained from the Health and Safety Department in the school. Bay Area Air Quality Management District in San Francisco sent the application forms to be completed by the owner of the system. Dr. Sonia Kreidenweis filled the forms out, and then returned it with a process flow diagram and a description of the system to them. One month later, a temporary permit by exemption was issued for operating the system.

The forms sent to them and the permit are shown in this section. For this application, the flame temperature and emission concentrations for our system are estimated as follows:

* Estimation of adiabatic flame temperature and equilibrium mole fractions of CO_2, CO, H_2O, H_2, O_2, N_2, NO, O, H, and OH when kerosene (87% C, 13% H) is burned at atmospheric pressure in stoichiometric air.

Known values: Gravity of kerosene: 0.8

Higher heating value (dhch): 19929 Btu/lb (46.352 KJ/g)

Initial fuel and air temp($T_a=T_f=T_0$): 298 K

Latent heat of vaporization of water at 298 K (dhv): 44000 J/mol

<1> The fuel (kerosene) composition is:

Element	Wt%	Normalize with respect to C
C	87/12=7.25	7.25/7.25=1.0
H	13/1=13.0	13.0/7.25=1.793

Effective Composition: CH1.793

Formula Weight: Mf = 12 + 1.793 = 13.79

<2> To find the enthalpy of formation, consider the combustion reaction.

$$CH1.8 + a\ (O2+3.78N2) \longrightarrow CO2 + 1.8/2\ H2O + a\ 3.78N2$$

For O, 2a = 2 + 0.9 = 2.9 a = 1.448

Thus,

$$CH1.8 + 1.448\ (O2 + 3.78N2) \longrightarrow CO2 + 0.9\ H2O + 5.48\ N2$$

<3> Enthalpy of formation of kerosene (dhf) may be determined using the lower heating value (dhcl) and the enthalpy of formation data.

dhf,CH1.8 (T0) = dhf,CO2 + 0.9 dhf,H2O - 1.448 dhf,O2 - dhcl

Since the higher heating value includes the latent heat of condensation of water vapor, the lower heating value is given by; LHV = HHV - VAP

$$-dhcl(T0) = -dhch(T0) - dhv$$

$$dhcl(T0) = dhch(T0) + dhv$$

$$dhch(T0) = Mf\ dhch = 13.8 \times (-46352\ J/g) = -639650\ J/mol$$

$$dhcl(T0) = -639650 + 0.896 \times 44000 = -600050\ J/mol\ C$$

Also $dhf,CO_2 = -394088$, $dhf,H_2O = -242174$, $dhf,O_2 = 0.0$

Thus, $dhf,CH_{1.8}(T0) = -394088 + 0.9*(-242174) - 1.448*(0) - (-602335) = -11995\ J/mol$

<4> Equilibrium relations are:

$$CO_2 + H_2 \rightleftharpoons CO + H_2O \qquad (1)$$

$$CO_2 \rightleftharpoons CO + 1/2\ O_2 \qquad (2)$$

$$1/2\ N_2 + 1/2\ O_2 \rightleftharpoons NO \qquad (3)$$

$$1/2\ H_2 \rightleftharpoons H \qquad (4)$$

$$1/2\ O_2 \rightleftharpoons O \qquad (5)$$

$$1/2\ H_2O + 1/4\ O_2 \rightleftharpoons OH \qquad (6)$$

<5> The equilibrium composition for stoichiometric combustion is determined. The overall process is

$$\begin{aligned} CH_{1.8} + 1.448\ O_2 + 5.747\ N_2 \longrightarrow\ & (1 - x)\ CO_2 + x\ CO \\ & + (0.9 - y - c - d)\ H_2O + y\ H_2 + c\ H + d\ OH \\ & + (x/2 + y/2 - a/2 - b/2 - d/2)\ O_2 + a\ NO + b\ O \\ & + (5.747 - a/2)\ N_2 \end{aligned}$$

For this system, the first law of thermodynamics becomes

$(1 - x)[h(T)-h(T0)+dhf(T0)]CO_2 + x[h(T)-h(T0)+dhf(T0)]CO +$
$(0.9 - y - c - d)[h(T)-h(T0)+dhf(T0)]H_2O + y[h(T)-h(T0)+$

dhf(T0)]H2 + c[h(T)-h(T0)+dhf(T0)]H

+ d[h(T)-h(T0)+dhf(T0)]OH + (x/2 + y/2 - a/2 - b/2 - d/2)

[h(T)-h(T0)+dhf(T0)]O2 + a[h(T)-h(T0)+dhf(T0)]NO

+ b[h(T)-h(T0)+dhf(T0)]O + (5.474 - a/2)[h(T)-h(T0)+

dhf(T0)]N2 + [h(Tf)-h(T0)+dhf(T0)]CH1.8 - 1.448[h(Ta)-h(T0)+

dhf(T0)]O2 - 5.474[h(Ta)-h(T0)+dhf(T0)]N2

= Q - Ws = 0

[h(T)-h(T0)]CO2 + 0.9[h(T)-h(T0)]H2O + 5.474[h(T)-h(T0)]N2 +

dhf,CO2(T0) + 0.9dhf,H2O(T0) - dhf,CH1.8(T0) -

1.448dhf,O2(T0) - 5.474dhf,N2(T0)

+ x{ [h(T)-h(T0)]CO + 1/2[h(T)-h(T0)]O2 - [h(T)-h(T0)]CO2

+ dhf,CO(T0) + 1/2dhf,O2(T0) - dhf,CO2(T0) }

+ y{ [h(T)-h(T0)]H2 + 1/2[h(T)-h(T0)]O2 - [h(T)-h(T0)]H2O

+ dhf,H2(T0) + 1/2dhf,O2(T0) - dhf,H2O(T0) }

+ a{ [h(T)-h(T0)]NO - 1/2[h)T)-h(T0)]O2 - 1/2[h(T)-h(T0)]N2

+ dhf,NO(T0) - 1/2dhf,O2(T0) - 1/2dhf,N2(T0) }

+ b{ [h(T)-h(T0)]O - 1/2[h(T)-h(T0)]O2 + dhf,O(T0) -

1/2dhf,O2(T0) }

+ c{ [h(T)-h(T0)]H - [h(T)-h(T0)]H2O + dhf,H(T0)

- dhf,H2O(T0) }

+ d{ [h(T)-h(T0)]OH - [h(T)-h(T0)]H2O - 1/2[h(T)-h(T0)]O2

+ dhf,OH(T0) - dhf,H2O(T0) - 1/2dhf,O2(T0) }

= 0

Note: The fuel and air temperature are initially Tf = Ta = T0 = 298K. Also,

hi(T)-hi(T0) = Cp,i(T')dT' = ai(T-T0) + bi/2(T^2 - T0^2)

Using the thermodynamic data,

Species	ai (J/molK)	bi (J/molK)	dhf,i(T0) (J/mol)	dSf,i(T0) (J/molK)
CO2	44.319	0.00730	-394088	213.984
H2O	32.477	0.00862	-242174	188.995
O2	30.5041	0.00349	0	205.310
N2	29.231	0.00307	0	191.777
CO	29.6127	0.00301	-110700	197.810
NO	30.5843	0.00278	90471	210.954
H2	27.3198	0.00335	0	130.770
H	20.7859	0.0	218300	114.773
OH	28.0743	0.00309	39520	183.858
O	21.2424	-0.0002	249553	161.181

(aCO2+0.9aH2O+5.48aN2)(T-T0) + 1/2(bCO2+0.9bH2O+5.48bN2)(T^2 -T0^2) + dhcl(T0)

+ x [(aCO+0.5aO2-aCO2)(T-T0) + 1/2(bCO+0.5bO2-bCO2)(T^2-T0^2) + dhf,CO2(T0) + 0.5dhf,O2(T0) - dhf,CO2(T0)]

+ y [(aH2+0.5aO2-aH2O)(T-T0) + 1/2(bH2+0.5bO2-bH2O)(T^2-T0^2) + dhf,H2(T0) + 0.5dhf,O2(T0) - dhf,H2O(T0)]

+ a [(aNO-0.5aO2-0.5aN2)(T-T0) + 1/2(bNO-0.5bO2-0.5bN2)(T^2-T0^2) + dhf,NO(T0) - 0.5dhf,O2(T0) - 0.5dhf,N2(T0)]

+ b [(aO-0.5aO2)(T-T0) + 1/2(bO-0.5bO2)(T^2-T0^2) + dhf,O(T0) - 0.5dhf,O2(T0)]

+c [(aH-aH2O)(T-T0) + 1/2(bH-bH2O)(T^2-T0^2) + dhf,H(T0) - dhf,H2(T0)]

+ d [(aOH-aH2O-0.5aO2)(T-T0) + 1/2(bOH-bH2O-0.5bO2)(T^2-T0^2) + dhf,OH(T0) - dhf,H2O(T0) - 0.5dhf,O2(T0)

= (0.01591 - 0.00127x - 0.00176y - 0.000251a - 0.000837b - 0.000985c - 0.001048d)T^2

+ (233.8775 + 0.54565x + 10.09525y + 0.7166a + 7.126b + 5.990c + 4.210d)T

- 670371 + 283338x + 239321y + 90229a + 216231b + 247853c + 159446d

= 0 ———————————————————————— (A)

For complete combustion, x = y = a = b = c = d = 0, and T = 2456 K. Incomplete combustion due to equilibrium will lower T. Since we expect that CO_2, CO, H_2O, H_2, O_2, and N_2 are main species, first neglect the amount of species (H, OH, NO, and O) which means a = b = c = d = 0. In order for x and y to be calculated, apply Van't Hoff's relationship and equilibrium conditions for first and second reactions in part <4>.

$$Kpi = (yi*P) = \exp\left[- \quad vix \frac{ui(T)}{RT}\right] \qquad \text{(B)}$$

$$Kp1 = [x / (1-x)] * [(0.9-y) / y] \qquad \text{(C)}$$

$$Kp2 = [y / (0.9-y)] * [(x+y) / (14.74+x+y)]\hat{}1/2 \qquad \text{(D)}$$

$$\begin{aligned} ui(T) &= hi - T*Si \\ &= Cp,i\ dT' + dhf,i(T0) - T\ [Si(T0) + \quad Cpi/T'\ dT'] \\ &= ai\ [T - T0 - T*\ln(T/T0)] - bi/2*(T-T0)\hat{}2 + dhf,i(T) \\ &\quad - T*Si(T) \qquad \text{(E)} \end{aligned}$$

Kp1 and Kp2 can be calculated at assumed T (2000 K) using equations (B) and (E).

$$Kp1 = 21.6 \exp(-3234/T) \qquad \text{(F)}$$

$$Kp2 = 22151 \exp(-33597/T) \qquad \text{(G)}$$

From equations (C), (D), (F), and(G), T, x, and y can be calculated. Let

$$f(x,y) = [x / (1-x)] * [(0.9-y) / y] - Kp1 = 0$$

$$g(x,y) = [x / (1-x)] * [(x+y) / (14.74+x+y)]\hat{}1/2 - Kp2 = 0$$

Beginning with a guess xg, yg, we need to iterate to find x and y that satisfy these conditions. This can be done using Newton's iteration. For this, we need the partial derivative of f anf g, i.e., df/dx = fx = [(0.9-y) / y] * [1 / (1-x)^2]

df/dy = fy = [x / (1-x)] * [0.9 / y^2]

dg/dy = gy = 1/2 * [x / (1-x)] * [(14.74+x+y) / (x+y)]^1/2
* [14.74 / (14.74+x+y)^2]

dg/dx = gx = [(x+y) / (14.74+x+y)]^1/2 * [1 / (1-x)^2] + gy

Using the guesses (xg,yg), an improved estimate can be determined by applying a Taylor series expansion,

0 = f(x,y) = f(xg,yg) + fx(xg,yg)*delx + fy(xg,yg)*dely

0 = g(x,y) = g(xg,yg) + gx(xg,yg)*delx + gy(xg,yg)*dely

Solving for the corrections, delx and dely, we find

delx = (f*gy - g*fy) / (gx*fy - fx*gy)

dely = (g*fy - f*gy) / (gx*fy - fx*gy)

For an initial guess, assume x = 0.1 and y = 0.01.
Iterations on x and y yield

Iterations	x	y
Initial	0.1	0.01
1	0.1698	0.02205
2	0.1136	0.01697
3	0.1253	0.02037
4	0.1230	0.02106

Applying the first law of thermodynamics (Equation (A)), we find T = 2358 K. Also, Kp1 = 5.4805 and Kp2 = 0.0144 using the equations (F) and (G). Iterating on the T, x, and y yields

T(K)	x	y
2358	0.1230	0.02106
2329	0.1128	0.02066
2338	0.1167	0.02133
2334	0.1149	0.02103
2336	0.1158	0.02118
2335	0.1154	0.02110
2335	0.1154	0.02110

Given x = 0.1154 and y = 0.02110, a, b, c, and d are then computed with initially assuming a = b = c = d = 0. The computations are then computed with the revised temperature estimate and the new parameters. The results are

T(K)	a	b	c	d	x	y
2308	0.02116	0.004	0.00288	0.02305	0.1187	0.02148

From which we find, the equilibrium compositions for stoichiometric air

	Without minor species	With minor species
T(K)	2335	2308
yCO2	0.118	0.1176
yCO	0.0155	0.0158
yH2O	0.118	0.1132
yH2	0.00284	0.00287
yO2	0.00917	0.00619
yN2	0.736	0.7307
yNO		0.00284
yO		0.000388
yH		0.000537
yOH		0.00310

<6> Emissions in ft3/hr and lb/hr can be computed from the flue gas flowrate in section 5.2;

* Actual flue gas at combustion conditions: 971.887 ft3/lb kerosene

* Actual flue gas flowrate for incineration of 9 cm3/min of kerosene:

  (9 cm3/min)*(1 liter/1000 cm3)*(7.4805 gal/28.316 liter)*(7 lb/gal) = 0.01664 lb kerosene/min

  (971.887 ft3/lb kerosene)*(0.01664 lb kerosene/min)

  = 16.1754 ft3 flue gas/min

  = 970.524 ft3 flue gas/hr

* Emissions in lb/hr can be computed using the ideal gas law.

$P*V = (m / M)*R*T$

$m(lb/hr) = (P*V*M) / (R*T)$

where P = Operating pressure (1 atm)

V = Emissions in ft3/hr

M = Molecular weight

R = Gas constant

T = Operating temperature (2200 F)

* Results for emissions in ft3/hr and lb/hr

	ft3/hr	lb/hr
CO_2	114.134	2.585
CO	15.334	0.221
H_2O	109.863	1.018
H_2	2.785	0.00287
O_2	6.008	0.0990
N_2	709.162	10.223
NO	2.756	0.0426
O	0.377	0.0031
H	0.521	0.00027
OH	3.009	0.0263

Concentration of SO2 can be computed as follows.

Since kerosene contain 0.1% by weight S (6), for 0.01664 lb/min (0.9984lb/hr) kerosene, 0.0009984 lb/hr of S will be out of the chamber. Thus feed contains

(0.0009984 lb S/hr) * (1 mol S/32 lb S) = 0.0000312 mol S/hr

Assume that 1 mol of S will be 1 mol of SO2.

Thus, the concentration of SOx is

(0.0000312 mol S/hr) * (1 mol SO2/1 mol S) * (64 lb/ lbmol SO2) = 0.002 lb SOx/hr.

Empirical emission concentrations for the incineration of kerosene with excess air are suggested by the COEN company, such as 0.0043 lbNOx/hr, 0.29lbCO/hr, and 0.0016 lbSOx/hr.

BAY AREA
AIR QUALITY MANAGEMENT DISTRICT
939 Ellis Street, San Francisco, CA 94109
(415) 771-6000

DATA FORM C
FUEL COMBUSTION SOURCE

District Use Only
New [ ]
Modified [ ]
Retro [ ]

Form C is for all operations which burn fuel. If the operation also involves evaporation of any organic solvent, complete Form S and attach to this form. If the operation involves a process which generates any other air pollutants, complete Form G and attach to this form.

[ ] Check box if this source has a secondary function as an abatement device for some other source(s); complete Lines 1, 2, & 7-13 on Form A (using the source number below for the Abatement Device No.) and attach to this form.

1. Company Name San Jose State University Plant No. ____ (If Unknown, Leave Blank) Source No. S____

2. Equipment Name and Number, or Description Liquid-Injection Incinerator Laboratory

3. Make, Model ____ Maximum Firing Rate 20,000 BTU/Hr

4. Date of Modification or Initial Operation ____

5. Primary Use (Check One): [ ] Electrical Generation [ ] Space Heat [ ] Waste Disposal [ ] Testing [ ] Abatement Device [ ] Cogeneration [ ] Resource Recovery [X] Other– instruc· [ ] Process Heat; Material Heated ____

6. SIC Number ____ (If Unknown, Leave Blank)

7. Equipment Type (Check One):

Internal Combustion: [ ] Diesel Engine [ ] Otto Cycle Engine [ ] Gas Turbine [ ] Other ____ — Displacement ____ cubic inches; ____ hp

Incinerator: [ ] Salvage Operation [ ] Liquid Waste [ ] Pathological Waste [X] Other fuels — Temperature 2200 °F; Residence Time 1 Sec

Others: [ ] Boiler [ ] Afterburner [ ] Flare [ ] Open Burning [ ] Other ____; [ ] Dryer [ ] Oven [ ] Furnace [ ] Kiln — Material dried, baked, or heated ____

8. [ ] Yes [X] No Overfire Air? If Yes, what percent (%) ____

9. [ ] Yes [X] No Flue Gas Recirculation? If Yes, what percent (%) ____

10. [ ] Yes [X] No Air Preheat? Temperature ____ °F

11. [ ] Yes [X] No Low NOx Burners? Make, Model ____

12. Maximum Flame Temperature 3500 °F

13. Combustion Products: Wet Gas Flow Rate 16 acfm at 2200 °F
Typical Oxygen Content ____ dry volume % or ____ wet volume %
or ____ % excess air based on stoichiometric air

14. Typical Use: Hours/Day .082 Days/Week ____ Weeks/Year ____ [based on 30 hours/year]

15. Typical % of Annual Total: Dec-Feb ____% Mar-May 50 % Jun-Aug ____% Sep-Nov 50 %

16. With regard to air pollutant flow, what source(s) or abatement device(s) are immediately upstream?
S____ S____ S____ S____ S____ S____ S____ A____ A____ A____

17. With regard to air pollutant flow, what source(s), abatement device(s), and/or emission points are immediately downstream?
S____ S____ A____ A____ P____ P____

10/82

Person Completing This Form S.M. Kreidenweis Date 7-27-90

FUELS

INSTRUCTIONS: Complete one line in Section A for each fuel. Section B is OPTIONAL. Please use the units at the bottom of each table. N/A means "Not Applicable".

SECTION A: Fuel Data

	Fuel Name	Fuel Code **	Total Annual Usage ***	Maximum Possible Fuel Use Rate	Typical Heat Content	Sulfur Content	Nitrogen Content (OPTIONAL)	Ash Content (OPTIONAL)
1.	nat. gas	189	(used for	pilot -	ignition	only)		
2.	oil	98	0.0033	0.00011				
3.								
4.								
5.								

Use the appropriate units for each fuel							
Natural Gas	Therms*	BTU/Hr	N/A	N/A	N/A	N/A
Other Gas	MSCF*	MSCF/Hr	BTU/MSCF	ppm	N/A	N/A
Liquid	MGAL*	MGAL/Hr	BTU/MGAL	wt %	wt %	wt %
Solid	TONS	Ton/Hr	BTU/Ton	wt %	wt %	wt %

SECTION B: Emission Factors (OPTIONAL)

	Fuel Name	Particulates Emission Factor	**Basis	NOx Emission Factor	**Basis	CO Emission Factor	**Basis	Other_____ Emission Factor	**Basis	Other_____ Emission Factor	**Basis
1.											
2.											
3.											
4.											
5.											

Use the appropriate units for each fuel	
Natural Gas	lb/Therm
Other Gas	lb/MSCF
Liquid	lb/MGAL
Solid	lb/Ton

NOTES:

* MSCF = thousand standard cubic feet
* MGAL = thousand gallons
* Therm = 100,000 BTU

** See tables below for Fuel and Basis Codes

*** Total Annual Usage is: Projected usage over next 12 months if equipment is new or modified.
: Actual usage for last 12 months if equipment is existing and unchanged.

FUEL CODES

CODE	FUEL	CODE	FUEL
25	Anthracite Coal	189	Natural Gas
33	Bagasse	234	Process Gas - Blast Furnace
35	Bark	235	Process Gas - CO
43	Bituminous Coal	236	Process Gas - Coke Oven Gas
47	Brown Coal	238	Process Gas - RMG
242	Bunker C Fuel Oil	237	Process Gas - Other
80	Coke	242	Residual Oil
89	Crude Oil	495	RDF
98	Diesel Oil	493	Sludge Gas
493	Digester Gas	256	Solid Propellant
100	Distillate Oil	257	Solid Waste
128	Gasoline	304	Wood - Hogged
158	Jet Fuel	305	Wood - Other
160	LPG	198	Other - Gaseous Fuels
165	Lignite	200	Other - Liquid Fuels
167	Liquid Waste	203	Other - Solid Fuels
494	Municipal Solid Waste		

BASIS CODES

CODE	METHOD
0	Not applicable for this pollutant
1	Source testing or other measurement by plant (attach copy)
2	Source testing or other measurement by BAAQMD (give date)
3	Specifications from vendor (attach copy)
4	Material balance by plant using engineering expertise and knowledge of process
5	Material balance by BAAQMD
6	Taken from AP-42 (Compilation of Air Pollutant Emission Factors, EPA)
7	Taken from literature, other than AP-42 (attach copy)
8	Guess

BAY AREA
AIR QUALITY MANAGEMENT DISTRICT
939 Ellis Street, San Francisco, CA 94109 (415) 771-6000

DATA FORM P
Emission Point

Form P is for well-defined emission points such as stacks or chimneys only; do not use for windows, room vents, etc.

Business Name: San Jose State University   Plant No.: ____________

Emission Point No.: P

With regard to air pollutant flow into this emission point, what source(s) and/or abatement device(s) are <u>immediately</u> upstream?

				S	S	S
S	S	S	A	A	A	A

Exit Cross-section Area: 0.05 Square feet   Height above grade: 15 Feet

Effluent Flow from Stack:

	Typical Operating Condition		Maximum Operating Condition	
Actual Wet Gas Flow Rate		cfm	16	cfm
Percent Water Vapor		Vol %	11	Vol %
Temperature		°F	2200	°F

If this stack is equipped to measure (monitor) the emission of any air pollutants,

-is monitoring continuous? yes

-what pollutants are monitored? CO, SO_2, NO_x

Person Completing this Form S.M. Kreidenweis   Date 7-30-90

4-25-77

PERMIT SERVICES DIVISION
BAY AREA AIR QUALITY MANAGEMENT DISTRICT
939 ELLIS STREET
SAN FRANCISCO, CA 94109
(415) 771-6000

PLANT DATA P-201

San Jose State University
BUSINESS NAME

OTHER BUSINESS NAME(S) [IF ANY]

NAME OF PARENT COMPANY [IF ANY]

PLANT IDENTIFICATION NUMBER
* PLANT IDENTIFICATION NUMBERS ARE ASSIGNED BY THE BAAQMD. LEAVE BLANK IF NUMBER IS NOT KNOWN.

[408] 924 - 4010
PLANT TELEPHONE NUMBER

PLANT ADDRESS 1 Washington Square
San Jose, CA 95192-0082
CITY STATE ZIP CODE

MAILING ADDRESS
CITY STATE ZIP CODE

PLANT AREA [ACRES]
NUMBER OF EMPLOYEES
PRINCIPAL PRODUCT

OWNERSHIP
[ ] PRIVATE
[ ] UTILITY
[ ] LOCAL GOVERNMENT
[X] STATE GOVERNMENT CSU System
[ ] FEDERAL GOVERNMENT

PLEASE SUBMIT A NAME AND ADDRESS TO WHOM
ALL CORRESPONDENCE REGARDING AIR POLLUTION
CONTROL CAN BE SENT.

S. M. Kreidenweis.
CONTACT NAME AND ADDRESS

Dept. of Chemical Engineering, SJSU
STREET ADDRESS

San Jose, CA 95192-0082
CITY STATE ZIP CODE

S. M. Kreidenweis, Assistant Professor
NAME AND TITLE OF PERSON PREPARING THIS FORM

July 31, 1990
DATE

PERMIT SERVICES DIVISION
BAY AREA AIR QUALITY MANAGEMENT DISTRICT
939 Ellis Street, San Francisco, CA. 94109
(415) 771-6000

BAAQMD PLANT NO.__________ **APPLICATION NO.**__________

APPLICATION FOR AUTHORITY TO CONSTRUCT AND PERMIT TO OPERATE INDUSTRIAL SOURCES

BUSINESS NAME San Jose State University, Department of Chemical Engineering

MAILING ADDRESS 1 Washington Square CITY/ZIP CODE San Jose 95192-0082

PLANT ADDRESS same CITY/ZIP CODE __________

NAME OF CONTACT S. M. Kreidenweis PHONE 408-924-4010

EQUIPMENT DESCRIPTION Liquid-Injection Incinerator Laboratory

NUMBER OF SOURCES [ ] NEW CONSTRUCTION [X] MODIFICATION [ ] REPLACEMENT [ ]

RELOCATION [ ] DEMOLITION OR SHUT DOWN [ ] TRANSFER OF OWNERSHIP [ ]

ABATEMENT EQUIPMENT ONLY [ ]

HAS AN ENVIRONMENTAL IMPACT REPORT (EIR) BEEN PREPARED FOR THIS PROJECT? YES____ NO X

IF YES, BY WHOM?__________

IS THIS APPLICATION A RESULT OF A VIOLATION NOTICE? YES____ NO X

IF YES, GIVE THE VIOLATION NOTICE NUMBER: __________

TOTAL EMISSIONS FOR THIS APPLICATION: __________

EMISSIONS IN LB/HR				
TSP	NMHC	SOx	NOx	CO
0	0	0.0016	0.0043	0.29

TYPICAL USAGE RATE: HOURS/DAY ______; DAYS/WEEK ______; HOURS per YEAR ~~WEEKS~~/YEAR 30

ARE OFFSETS OR TRADEOFFS INVOLVED IN THIS APPLICATION? YES____ NO X

IF YES, GIVE DOCUMENTS AND PAGE NUMBERS ON WHICH THIS INFORMATION IS PROVIDED: __________

(OVER)

HAVE YOU PROVIDED AN AIR QUALITY ANALYSIS? YES _____ NO __X__

IF YES, GIVE DOCUMENTS AND PAGE NUMBERS ON WHICH THIS INFORMATION IS PROVIDED: __________

____

THE FOLLOWING ITEMS SHOULD ACCOMPANY THIS APPLICATION:
(a) Process Flow Diagram (if applicable) and; (b) a description or manufacturer's catalogue of equipment and air pollution abatement equipment. (See AB884 -Lists and Criteria for further details.

IMPORTANT: All information that you submit will be considered as public information unless you indicate that it is considered TRADE SECRET and give the reasons.

[X] ACKNOWLEDGEMENT

SIGNATURE S.M. Kreidenweis TITLE Assistant Professor

NAME (PRINTED) S.M. Kreidenweis DATE July 28, 1990

NOTE: PERMITS FOR YOUR PROJECT MAY ALSO BE REQUIRED FROM OTHER AGENCIES. FOR FURTHER INFORMATION, YOU SHOULD CONTACT THE LOCAL CITY OR COUNTY OFFICE IN WHICH THE PROPOSED PROJECT WILL BE LOCATED. ALSO, THE OFFICE OF PERMIT ASSISTANCE WITHIN THE OFFICE OF PLANNING AND RESEARCH IN SACRAMENTO IS AVAILABLE TO PROVIDE INFORMATION ON PERMITTING. THE ADDRESS IS AS FOLLOWS:

OFFICE OF PLANNING AND RESEARCH
1400 Tenth Street
Sacramento, California 95814

FORM P-101B
Revised 9/86
jrb

Appendix E. Operating Manual Instructions

These instructions consist of two parts: part one is for operating the incineration process, and part two is for operating the data acquisition system.

Part 1. Operating the Incineration Process

(I) Start Up Procedures

1. Make sure all supply lines are closed.
2. Supply power to the cabinet.
3. Open the oil supply valve (for incineration of the oil only).
4. Supply power to the oil pump.
5. Make sure the right range of pressure of compressed air (25 - 35 psi).
6. Open the atomizing air valve.
7. Make sure natural gas pressure in a range (8 - 12 in H2O).
8. Close the vent valve of the gas line.
9. Open the natural gas supply valve.
10. Put the PLC in RUN mode.
    - (a) Press RUN button.
    - (b) Press +/- button until <RUN Mode> appears.

(c) Press Enter button.

11.Follow the procedure for specific incineration type.

(II) Procedures Specific to Fuel Used

*** Procedures for incineration of natural gas only ***

1. Select gas (Gas Selection Switch).
2. Turn on the key (ON/OFF Switch).
3. Push the Purge Start button.

   Wait for the Purge Complete Indicator on for 2 minutes.

   Wait for the Natural Gas Limits Indicator on.
4. Push the Pilot Start button.

   Wait for the Pilot Indicator on.
5. Push the Main Gas Start button.

   Wait for the Gas On Indicator on.
6. Push the Stop button when done.

   Wait for the air fan to go off (2 minutes).
7. Turn off the key (ON/OFF Switch).

*** Procedures for incineration of light oil only ***

1. Select oil (Oil Selection Switch).
2. Turn on the key (ON/OFF Switch).
3. Push the Purge Start Button.

   Wait for the Purge Complete Indicator on (2 minutes).

   Wait for the Natural Gas Limits Indicator on.
4. Push the Pilot Start button.

Wait for the Pilot Indicator on.

5. Push the Oil Start button.

   Wait for the Oil Indicator on.

6. Push the Stop button when done.

   Wait for the air fan to go off (2 minutes).

7. Turn off the key (ON/OFF Switch).

*** Procedures for incineration of heavy viscosity oil ***

1. Select the Gas and Oil Switch.

2. Turn on the key (ON/OFF Switch).

3. Push the Purge Start button.

   Wait for the PUrge Complete Indicator on (2 minutes).

   Wait for the Natural Gas Limits Indicator on.

4. Push the Pilot Start button.

   Wait for the Pilot Indicator on.

5. Push the Main Gas Start button.

   Wait for the Gas On Indicator on.

6. Push the Oil Start button.

   Wait for the Oil On Indicator on.

7. Push the Stop button when done.

   Wait for the air fan to go off (2 minutes).

8. Turn off the key (ON/OFF Switch).

(III) Normal Shut Down Procedures

1. Put the PLC in Stop mode.
   (a) Press RUN button.
   (b) Press +/- button until <STOP Mode> appears.
   (c) Press Enter button.
2. Open the vent valve of the gas line.
3. Close the oil, atomizing air, and natural gas supply valves.
4. Shut off power to the cabinet.

(IV) Emergency Shut Down Procedures

The conditions, which described in section 7.1 D′, need corrective action to restart the system.

1. Push the Stop button.
   Wait for the air fan to go off (2 minutes).
2. Put the PLC in STOP mode.
   (a) Press RUN button.
   (b) Press +/- button until <STOP Mode> appears.
   (c) Press Enter button.
3. Go back to step 3 in part (II).

For example, if the flame is out because of underpressure of natural gas, the solenoid valves for the main gas, pilot gas, and oil lines will be shut off automatically. The indicator lights of main gas, oil, pilot, and gas pressure limits will be off. In this case, restart the system following the emergency shut down procedures.

Part 2. Operating the Data Acquisition System

(I) Start Up the Emission Analyzer

1. Insert the water trap into the opening provided that is located on the hinged side of the faceplate.
2. Connect the hose end of the stack probe to the top of the water trap, and the RS-232 cable end to its corresponding connector on the faceplate.
3. Turn the analyzer on. Make sure that the "Battery OK" light on. The Display should read: "Press ENTER to AUTOZERO".
4. Press the ENTER key.

(II) Start up the Data Acquisition System

5. Supply power to the computer and the data acquisition metal box.
6. Turn on the computer.
7. Type CD\123, and press ENTER to change directory.

(III) Store the Data from the Emission Analyzer Using RS-232 Module

8. Type 123 RS-232, and press ENTER.
9. Type /FR, select TEST.WK1, and press ENTER to retrieve the file which is used for storage of data.
10. Press ALT and F9 simultaneously to get into the main manu of the RS-232 module.
11. Type SNR, and press ENTER to retrieve the file (GAS.RCF) which contains information for data acquisition between the instrumentations and the computer. If any information needs to be changed, do it following the instruction of the Data Acquisition Module Reference.
11. Type Q.
12. Select CAPTURE-RANGE, and press ENTER to collect the data from the emission analyzer. A rectangular line will be shown on the computer screen.
13. Press TEXT on the emission analyzer as soon as possible in order for the data to be transferred to the computer.
14. Press ENTER to store the data.
15. Type /FS, press ENTER, and select REPLACE to save the data in the file.
16. Type /QY to get out of the RS-232 module.

(IV) Store the Data of Temperatures and Flow Rates Using Lab-PC Module

17. Type 123 MIO, and press ENTER.
18. Type /FR, and select TEST.WK1, and press ENTER to retrieve the file which is used for storage of data.
19. Press ALT and F8 simultaneously to get into the main manu of the Lab-PC module.
20. Type INR, and press ENTER to retrieve the file (ANALOG.ACF) which contains information for data acquisition between the instrumentations and the computer. If any information needs to be changed, do it following the instruction of the Data Acquisition Module Reference.
21. Type Q.
22. Type G to acquire the data, temperatures and flow rates. Wait until the main menu appears.
23. Type Q. All data will be on the computer screen.
24. Type /QY to get out of this file.

Appendix F. Federal Regulation and Standards [25]

Two types of standards are established to protect the public health; Ambient Air Quality Standards (AAQS's), which deal with concentrations of pollutants in the outdoor atmosphere, and National Source Performance Standards (NSPS's), which apply to emissions of pollutants from specific sources. AAQS's are written in terms of concentration (ug/m3 or ppm), and have been established for six groups of pollutants: particulates (of any kind), sulfur oxides, nitrogen oxides, carbon monoxide, ozone, and lead. These standards are presented in Table 16. Primary standards were established to protect the public health, whereas the secondary standards were established to protect the public well-being.

NSPS's, which are written in terms of mass emissions per unit of time or unit of production (g/min or kg of pollutant per ton of product produced), are derived generally from actual field tests at a number of industrial plants. Some examples are given in Table 17.

PLEASE NOTE

Copyrighted materials in this document have not been filmed at the request of the author. They are available for consultation, however, in the author's university library.

Appendix F, Federal Regulation and Standards, 165-168

University Microfilms International